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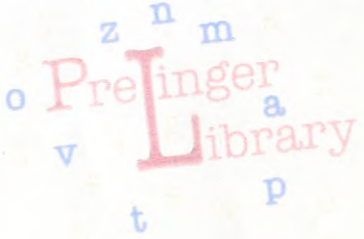

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CONTENTS

TECHNICAL BULLETIN NO. 301.—THE PUBLIC DOMAIN OF NEVADA AND FACTORS AFFECTING ITS USE (E. O. Wooton) : Page

Introduction 1
The physical limitations 3
Size 3
Surface relief 4
Climate 4
Erosion 6
Plant cover 7
The forage resources 8
Forage-plant associations and their distribution 9
Grazing capacity 16
The water supply and its use 17
The control of the land and its utilization 19
Methods used in this study 22
The range stockmen 24
The farmers 28
The miscellaneous class 29
Important steps in the development of the livestock industry 31
The legal status of the public domain 37
The recorded range claims 40
Summary and conclusions 44
Bibliography 50

TECHNICAL BULLETIN NO. 302.—COTTON IMPROVEMENT THROUGH TYPE SELECTION, WITH SPECIAL REFERENCE TO THE ACALA VARIETY (O. F. Cook) :

General problems of selection in cotton 1
Need for continued selection 1
Precautions commonly overlooked 3
Selection to maintain adaptation 4
Nature and effects of selection 7
Breeding for novelties 9
Limitations of the pure-line theory 10
Effects of continued line breeding 12
Systems of selection defined and illustrated 13
Four systems of selection 13
Comparison of systems 14
Type selection and progeny selection 15
Simplified type selection 17
Recognizing and maintaining a superior type 18
Selection for preserving a type 21
Differences among type progenies 25
Significance of progeny drift 26
Cotton variations underlying the application of selection 28
Individual boll fluctuations 28
Abnormal variations of bolls 29
Uniformity an essential in cotton breeding 30
Visible and invisible characters 36
Earliness characters 39
Resistance to adverse conditions 44
Stress effects and growth disorders 48

TECHNICAL BULLETIN No. 302.—COTTON IMPROVEMENT THROUGH TYPE SELECTION, WITH SPECIAL REFERENCE TO THE ACALA VARIETY—Con. Page

Field conditions and precautions in selection 50
Choice of conditions for selection 50
Conditions for roguing 51
Precautions with select strains 52
Methods of testing progenies 53
Comparing type progenies in groups 55
Progeny comparisons in different places 57
Summary and conclusions 58
Literature cited 60

TECHNICAL BULLETIN No. 303.—ECONOMIC UTILIZATION OF MARGINAL LANDS IN NICHOLAS AND WEBSTER COUNTIES, W.VA. (Millard Peck, Bernard Frank, and Paul A. Eke):

Introduction 1
Geographic characteristics and economic development of Nicholas and Webster Counties and the surrounding area 4
Economic development of Nicholas and Webster Counties 5
Economic organization of the section 7
Differentiation of farm and other land—agricultural phases of the problem 9
Relationship of soil type to farm economy 13
Soil type and crops 15
Soil type and livestock enterprises 17
Relationship of topography to farm economy 17
Topography and crops 19
Topography and livestock 19
Combined effect of soil type, topography, and size of farm on farm income 20
The community as a factor in drawing the line between farm and other land 20
Forestry aspects of the land-utilization problem 25
The present situation 25
Changes in extent and character of forest resources 39
Trend in ownership 40
Possibilities of forest lands under management 40
Rates of growth of individual species 41
Growth of mixed, uneven-aged stands 42
Growth of even-aged old-field stands 43
Yields of saw timber 43
Combination of various products 47
Management of farm woodland 49
Costs of holding timberland 51
Outlines of an economic program for the Nicholas-Webster section 53
Economic program for farming 53
Public acquisition of scattered farms 54
Cost of government 54
Forest industries 55
Consolidation and management of farm woodlands 56
Consolidation and management of large tracts 57
Cutting policies 58
Protection from fire 59
Public assistance in private forestry 59
Public acquisition of forest land 60
The place of schools in the regional program 61
Roads in relation to regional planning 62
Extent of area in West Virginia to which results of this study probably apply 63
Literature cited 64

TECHNICAL BULLETIN No. 304.—AN ALINEMENT-CHART METHOD FOR PREPARING FOREST-TREE VOLUME TABLES (L. H. Reineke and Donald Bruce):

Introduction 1
The base chart for volume tables of entire stem in cubic feet 3
Assembly of the data 5

TECHNICAL BULLETIN No. 304.—AN ALINEMENT-CHART METHOD FOR PREPARING FOREST-TREE VOLUME TABLES—Continued Page
The first correction of the chart 6
The second correction of the chart 8
The third correction of the chart 14
Fourth and subsequent corrections of the chart 15
The number of approximations necessary 15
Final preparation of the volume table 15
Measures of accuracy of the final table 17
A permissible short cut in reading the second estimates 17
The order in which the corrections are made 17
Tables of volume in cubic feet of entire stem, including bark 19
Tables based on d.b.h. inside of bark 19
The form of base chart for merchantable volume in cubic feet 19
The form of base chart for merchantable volume in board feet 21
The technic in the case in the board-foot tables 24
The advantages of the alinement-chart method 28

TECHNICAL BULLETIN No. 305.—THE STRENGTH AND RELATED PROPERTIES OF REDWOOD (R. F. Luxford and L. J. Markwardt):
Introduction 1
Purpose 3
Nature of studies 3
Specific gravity survey 3
Specific gravity and variation 4
Specific gravity as affected by distance from pith 5
Specific gravity as affected by height in tree 6
Specific gravity variation among trees 6
Specific gravity as affected by site classification 8
Specific gravity as related to region of growth 9
Specific gravity as related to rate of growth 11
Effect of specific gravity on the utility of second-growth redwood 11
Description of test material and method of testing for strength 12
Results of strength tests on virgin-growth redwood 13
Results of strength tests on second-growth redwood 16
Factors affecting the properties and uses of redwood 16
Relation between specific gravity and strength 16
Relation between moisture and strength 20
Strength as related to height in tree 20
Moisture distribution within the tree 20
Properties as affected by extractives 21
Radial and tangential shrinkage 22
Compression wood and endwise shrinkage 23
Comparison of the strength of compression wood and normal redwood 24
Summary 25
Appendix 25
Detailed data from the specific gravity survey 25
Detailed data on strength and associated properties of redwood 34
Explanation of terms and methods employed 41
Literature cited 48

TECHNICAL BULLETIN No. 306.—BIOLOGY AND CONTROL OF THE CORN-LEAF APHID WITH SPECIAL REFERENCE TO THE SOUTHWESTERN STATES (V. L. Wildermuth and E. V. Walter):
Introduction 1
History of the corn-leaf aphid in the United States 2
Distribution 2
Food plants 5
Field history 7
Type and extent of injury 7
Life history 8
Cages used in life-history studies 9
Difficulties encountered 10
Generation experiments 10
Length of instars 12
Viviparous forms 12

TECHNICAL BULLETIN No. 306.—BIOLOGY AND CONTROL OF THE CORN-LEAF APHID WITH SPECIAL REFERENCE TO THE SOUTHWESTERN STATES—Con. Page

Sexual forms 13
Males 14
Description of male *Aphis maidis* 15
Natural checks 16
Adverse weather conditions 16
Insect and other enemies 17
Control 19
Time of planting 19
Pasturing 19
Spraying and dusting 19
Summary 19
Literature cited 20

TECHNICAL BULLETIN No. 307.—CRESTED WHEATGRASS AS COMPATED WITH BROMEGRASS, SLENDER WHEATGRASS, AND OTHER HAY AND PASTURE CROPS FOR THE NORTHERN GREAT PLAINS (H. L. Westover, J. T. Sarvis, Leroy Moomaw, George W. Morgan, John C. Thysell, and M. A. Bell):

Introduction 1
History 2
Description 3
Characteristics 3
Adaptation 5
Culture 7
Seed bed 7
Time of seeding 7
Method of seeding 8
Rate of seeding 12
Cultivation 12
Composition 13
Experiments at Dickinson, N.Dak 13
Experiments at Mandan, N.Dak 15
Utilization 16
As a hay crop 16
Relation of age of stand to productivity 26
For pasture 27
For improvement of range and reseeding abandoned plowed areas 29
For lawns 29
Seed production 30
Viability of seed 32
Diseases 32
Weed control 33
Summary 33
Literature cited 34

TECHNICAL BULLETIN No. 308.—BIOLOGY OF SOME JAPANESE AND CHOSENESE GRUB PARASITES (SCOLIIDAE) (Curtis P Clausen, T. R. Gardner, and Kaku Sato):

Introduction 1
Host relationships 2
The life cycle 4
Number of generations 4
Length of the egg stage 5
Length of the larval stage 6
Time passed in the cocoon 7
Length of adult life 7
Feeding habits of adults 8
Oviposition 10
Paralysis of the host 10
Manner of oviposition 10
Position of the egg 12
Number of eggs 14
Host mortality through mechanical injury 15

TECHNICAL BULLETIN NO. 308.—BIOLOGY OF SOME JAPANESE AND CHOSENESE GRUB PARASITES (SCOLIIDAE)—Continued

Page

The immature stages 16
The egg 16
The larva 17
The cocoon 19
Parthenogenesis 21
Natural enemies 21
Summary 24
Literature cited 25

TECHNICAL BULLETIN NO. 309.—THE DEVELOPMENT OF PACKAGE-BEE COLONIES (W. J. Nolan):

Introduction 1
Previous data on development of package-bee colonies 3
Package-bee investigations at the bee-culture laboratory 6
General method of obtaining and working up data 6
Experiments in 1926 9
Experiments in 1927 12
Discussion of facts brought out in 1927 by package colonies as a whole 19
Weight of live bees in package on arrival in comparison with weight billed by shipper 19
Relation between number of bees in package as computed on basis of individual sample and basis of 5,000 bees to the pound 22
Importance of quantity of bees in package 25
Relation between size of package and rapidity of building up 25
Actual length of time necessary for building up 29
Importance of bees of proper age 32
Length of time on road 33
Effect of weather conditions at time of installation 34
Use of sirup when installing packages 34
Effect of presence or absence of a queen bee in the package during shipment 35
Balling the queen bee 36
Importance of time when the queen bee is released 36
Importance of a prolific queen bee 37
Package bees as pollenizers 38
Package bees as honey gatherers 39
Summary 41
Literature cited 42

TECHNICAL BULLETIN NO. 310.—THE VISUAL SPECTROPHOTOMETRY OF DYES (W. C. Holmes, J. T. Scanlan, and A. R. Peterson):

Introduction 1
Color and absorption 1
Color and chemical constitution 3
Equipment and technic for visual spectrophotometry 4
The influence of conditions upon absorption 8
Solvent 8
Dye concentration 10
Temperature 12
Colloidal state 14
Hydrogen-ion concentration 15
The identification of dyes 16
The spectroscopic method 17
The spectrophotometric method 18
Absorption ratios 21
The spectrophotometric evaluation of dyes 25
Individual dyes 25
Dye mixtures 30
Spectrophotometric evaluation and practical dye testing 34
Indicator methods 35
Literature cited 39

TECHNICAL BULLETIN No. 311.—ADEQUACY AND RELIABILITY OF CROP-YIELD ESTIMATES (Charles F. Sarle): Page

Introduction 1
Purpose and procedure 4
Sources and kinds of information 5
Phenomena of crop yields 5
The lists of reporters 7
Judgment inquiries 7
Reports for individual farms 9
Census enumerations 10
Commercial checks 11
Preparation of the estimates 11
Adequacy of sample data 12
The problem 12
Representatives of yield samples 15
Methods of selecting a representative sample 19
Errors encountered and their treatment 23
Measures of precision of averages 28
Statistical induction 36
Reliability of the estimates for selected crops 39
Procedure 40
Winter wheat 46
Spring wheat 56
Rye 60
Corn 63
Oats 70
Barley 73
Cotton 75
Tobacco 80
Potatoes 83
Sweetpotatoes 87
Tame hay 88
Flaxseed 92
Buckwheat 93
Field beans 95
Peanuts 96
Rice 97
Other minor crops 98
Dispersion of yield samples 99
Probable errors of the averages of yield samples 100
Comparison of yield estimates of the Department of Agriculture and yields derived from census data 101
Wheat 117
Corn 120
Oats 122
Flaxseed 122
Cotton 124
Tobacco 126
General considerations in regard to comparisons of yield estimates 128
Estimates of yield per acre, 1866 to 1925 129
Size of sample 129
Representativeness 132
Bias 132
Conclusions 133
Literature cited 137

TECHNICAL BULLETIN No. 312.—RESPONSE OF SWEET CORN TO VARYING TEMPERATURES FROM TIME OF PLANTING TO CANNING MATURITY (C. A. Magoon and Charles W. Culpepper):

Introduction 1
Sources of data 2
The temperature base line 2

TECHNICAL BULLETIN NO. 312.—RESPONSE OF SWEET CORN TO VARYING TEMPERATURES FROM TIME OF PLANTING TO CANNING MATURITY—Con. Page

Meteorological data for 1924 and 1927 4
Results with Golden Bantam in 1924 7
Results with Golden Bantam in 1927 10
Air-temperature summations 10
Soil-temperature summations 13
Results with Stowell Evergreen in 1924 15
Results with Stowell Evergreen in 1927 17
Air-temperature summations 17
Soil-temperature summations 19
Discussion of results with Golden Bantam and Stowell Evergreen in 1924 and 1927 21
Temperature summations for different varieties 22
Data from corn grown in Iowa 24
Data from corn grown in Maine 26
Data from corn grown in New York 32
General discussion 33
Summary 37
Literature cited 39

TECHNICAL BULLETIN NO. 313.—STUDIES OF PHYSIOLOGIC SPECIALIZATION IN PUCCINIA TRITICINA (C. O. Johnston and E. B. Mains):

Introduction 1
History 2
Materials and methods 3
Differential or standard varieties 3
Methods of study 5
Infection types and reaction classes 7
Experimental results 10
Coordination of published and new data dealing with physiologic specialization in *Puccinia triticina* 10
Relationship and variations of physiologic forms 13
Distribution and prevalence of physiologic forms of *Puccinia triticina* in the United States and Canada 15
General discussion 19
Summary 21
Literature cited 21

TECHNICAL BULLETIN NO. 314.—FACTORS AFFECTING THE DEVELOPMENT OF THE AECIAL STAGE OF PUCCINIA GRAMINIS (Ralph U. Cotter):

Introduction 1
Historical review 2
Methods and materials 3
Experimental results 4
Susceptible and resistant varieties of Berberis 4
Germination of teliospores 10
Relation of age and freezing of teliospores to infection of barberries 13
Relation of temperature to infection of barberries 13
Influence of light on infection of barberries 15
Time required for infection of *Berberis vulgaris* with teliospores of *Puccinia graminis secalis* 16
Susceptibility of barberry leaves of various ages and species 21
Effect of length of incubation period on infection of barberries 24
Effect of temperature and moisture on development of aecia 24
Effect of freezing on rusted barberry 25
Effect of light on development of aecia 28
Conditions for liberation of aeciospores 28
Viability of aeciospores 30
Physiologic forms within a single aecium 31
Discussion 34
Summary 36
Literature cited 37

TECHNICAL BULLETIN NO. 315.—SOIL SURVEY (RECONNAISSANCE) OF ST. CROIX ISLAND, VIRGIN ISLANDS (James Thorp):

	Page
Area surveyed	1
Climate	3
Agriculture	5
Soils and crops	8
Soils of group 1	11
Soils of group 2	13
Soils of group 3	17
Soils of group 4	18
Irrigation and alkali	19
Soils and their interpretation	20
Summary	27

TECHNICAL BULLETIN NO. 316.—PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS (H. E. Middleton, C. S. Slater, and Horace G. Byers):

Introduction	1
Outline of investigation	2
Experimental methods	3
Description of soil samples	3
Houston series	3
Kirvin series	4
Vernon series	4
Shelby series	5
Colby series	6
Cecil series	6
Palouse series	8
Marshall series	8
Composition and properties of the profile samples	9
Physical properties	9
Chemical composition of the soils	19
Chemical composition of the colloids	23
Properties of composite plot samples	34
Run-off and erosion data	43
General remarks	48
Summary	48
Literature cited	49

TECHNICAL BULLETIN NO. 317.—A CRITICAL LABORATORY REVIEW OF METHODS OF DETERMINING ORGANIC MATTER AND CARBOHYDRATES IN SOIL (Lyle T. Alexander and Horace G. Byers):

Introduction	1
The hydrogen peroxide method	2
Experimental data	3
The combustion method	14
The organic factor	14
Loss on ignition	18
Experimental data	18
Comparison of the methods	21
Summary	23
Literature cited	23

TECHNICAL BULLETIN NO. 318.—EFFECT OF SOLID AND GASEOUS CARBON DIOXIDE UPON TRANSIT DISEASES OF CERTAIN FRUITS AND VEGETABLES (Charles Brooks, E. V. Miller, C. O. Bratley, J. S. Cooley, Paul V. Mook, and Howard B. Johnson):

Introduction	1
Review of literature	2
Purpose of the investigation	5
Methods and apparatus	6
Experiments at constant temperatures	6
Experiments in pony refrigerators	7
Experiments in standard refrigerator cars	7
Strawberry experiments	8
Strawberries at constant temperatures	9
Strawberries in pony refrigerators	13
Strawberries in refrigerator cars	17

TECHNICAL BULLETIN NO. 318.—EFFECT OF SOLID AND GASEOUS CARBON DIOXIDE UPON TRANSIT DISEASES OF CERTAIN FRUITS AND VEGETABLES—Continued

Page

Peach experiments 21
Peaches at constant temperatures 22
Peaches in pony refrigerators 26
Peaches in refrigerator cars 31
Dewberry experiments 36
Dewberries in pony refrigerators 37
Dewberries in refrigerator cars 40
Experiments with other fruits and with vegetables 44
Blackberries 44
Raspberries 45
Blueberries 45
Currants 45
Apricots 45
Cherries 46
Plums and prunes 46
Pears 49
Apples 51
Grapes 52
Oranges and mangos 53
Tomatoes, string beans, and peas 53
Corn, carrots, and cauliflower 53
Discussion 54
Summary 56
Literature cited 58

TECHNICAL BULLETIN NO. 319.—THE FRACTIONATION, COMPOSITION, AND HYPOTHETICAL CONSTITUTION OF CERTAIN COLLOIDS DERIVED FROM THE GREAT SOIL GROUPS (Irvin C. Brown and Horace G. Byers):

Introduction 1
Preliminary study 3
Description of samples 5
Method of extraction of the colloid fractions 7
Methods and results of the examination of the fractions 9
Water vapor absorption and heat of wetting 21
The difficultly extractable colloid 26
Water vapor absorption of the difficultly extractable colloid 30
The Pasteur-Chamberland filtrate 31
General discussion 33
Summary 40
Literature cited 42

TECHNICAL BULLETIN NO. 320.—THE CITRUS BLACKFLY IN ASIA AND THE IMPORTATION OF ITS NATURAL ENEMIES INTO TROPICAL AMERICA (Curtis P. Clausen and Paul A. Berry):

Foreword (by C. L. Marlatt) 1
Introduction 3
The citurus blackfly 4
Distribution 4
Status as a citrus pest in the Far East 7
Host plants 8
Life history and habits 10
Mortality factors 11
Climatic conditions in the infested regions 13
Relation of meteorological conditions to blackfly development 16
Comparison with Florida and California 17
Potential status of the blackfly in the United States 19
Natural enemies of the citrus blackfly 19
Parasites in tropical Asia 20
Predators in tropical Asia 36
Native predators in Cuba, Panama, and Jamaica 45
Fungous diseases 46
Methods of rearing, shipment, and colonization 47
Summary 56
Literature cited 58

TECHNICAL BULLETIN NO. 321.—REPRODUCTION AND HEALTH RECORDS OF THE BELTSVILLE HERD OF THE BUREAU OF DAIRY INDUSTRY (Fred W. Miller and R. R. Graves):

Page

Introduction 1
Fertility of cows and heifers 2
Services required for conception 3
Distribution of services 4
Comparison of cows and heifers 6
Prevalence of sterility 6
Ages at which sterility occurs 7
Fertility of bulls 7
Effect of season upon fertility 8
Comparison of young and aged bulls 8
Results of pregnancies terminated 9
Living calves, abortions, and calves born dead 10
Effect of age on calving efficiency 11
Causes and treatments of sterility 12
Removal of persistent corpora lutea 12
Reducing ovarian cysts 13
Atresic follicles 13
Inflammation of genital organs 14
Exercise 14
Feeding sprouted oats to correct sterility 15
Control of abortion disease 17
Other abnormal conditions encountered, treatments, and fatalities 19
Nutritional disturbances 19
Foreign bodies 20
Lung troubles 20
Udder troubles 20
Injuries and lameness 20
Miscellaneous troubles 21
Discussion and summary 21

TECHNICAL BULLETIN NO. 322.—AGRICULTURAL CREDIT CORPORATIONS AFFILIATED WITH COTTON COOPERATIVE MARKETING ASSOCIATIONS (William H. Rowe):

Introduction 1
Characteristics of organization 5
Capital-stock features 5
The stockholders 6
Control and management 6
Relationship between the corporations and the cotton associations 7
Types of loans 8
Production credit loans 8
Harvest loans 8
Loans to obtain delivery at picking time 9
Supplementary loans on pooled cotton 9
Miscellaneous types of loans 10
Operating practices 11
Procedure in making loans 11
Control and follow-up of use of funds 13
Collection of loans 14
Loan requirements 14
Considerations in passing upon loans 14
Rejections 15
Limits to size of loans 15
Security for loans 16
Term of loans 18
Loan experience 18
Volume of loans 18
Size of loans 21
Carry-over 23
Losses 25
Rediscount relations with the Federal intermediate credit banks 26
Lines of credit and excess-collateral requirements 26
Volume of rediscounting 28

TECHNICAL BULLETIN NO. 322.—AGRICULTURAL CREDIT CORPORATIONS AFFILIATED WITH COTTON COOPERATIVE MARKETING ASSOCIATIONS—Continued.
Rediscount relations with the Federal intermediate credit banks—Continued Page
Rediscount rates and margins allowed 32
The banks' examination of loans 33
Causes of dissatisfaction 33
Costs of loans to the borrower 33
Rate of interest 34
Factors modifying rate of interest in ascertaining cost to borrower 35
Final cost to the borrower 37
Income, costs, and profits 39
Operating statements 39
Operating figures per loan and per dollar of loan 41
Reasons for small profits 42
Comparison with earnings and expenses of banks 44
Supplementary sources of income 46
Income-tax provisions 46
Dividends, reserves, and surpluses 47
Special problems of credit corporations 47
Ownership of stock by borrowers 47
Local loan groups 50
Extent of affiliation with cooperative marketing association 51
Excessive hazards of the loans 52
An appraisal of the corporations 54
Agricultural credit corporations as a source of credit for farmers 54
State-wide operations 57
Relations with cooperative marketing associations 58
Conclusions 60
Appendix 62
Contract between Growers Agricultural Credit Corporation and members of local groups 62

TECHNICAL BULLETIN NO. 323.—SECOND-GROWTH YIELD, STAND, AND VOLUME TABLES FOR THE WESTERN WHITE PINE (Irvine T. Haig):
Introduction 1
Definitions of terms used 2
Discussion of yield tables 3
Basis and scope 3
Western white pine yields 5
Height growth and site index 6
Number and size of trees 8
Cubic-foot volumes 9
Board-foot volumes 9
Increment and rotation age 12
Predicting the yields of second-growth stands 13
Age determination 14
Site determination 15
Determination of stocking 15
Other features of application 17
Discussion of stand tables 17
Application of stand tables 18
Effect of stocking and composition 18
Discussion of volume tables 19
Yield tables 19
Total stand 19
Trees 6.6 inches d.b.h. and larger 21
Trees 7.6 inches d.b.h. and larger 22
Trees 12.6 inches d.b.h. and larger 22
Dominant stand 24
Stand tables 25
Volume tables 30
Cubic-foot volumes 30
Board-foot volumes, Scribner rule 37
Board-foot volumes, international rule 44

TECHNICAL BULLETIN No. 323.—SECOND-GROWTH YIELD, STAND, AND VOLUME TABLES FOR THE WESTERN WHITE PINE—Continued Page

Appendix 54
Yield-table material and technic 54
Statistical analysis of results 59
Stand-table material and technic 62
Volume-table material and technic 63
Literature cited 66

TECHNICAL BULLETIN No. 324.—AN ECONOMIC STUDY OF THE PECAN INDUSTRY (S. A. Jones, V. C. Childs, R. S. Washburn, B. H. Thibodeaux, J. W. Park, and H. E. Rutland):

Introduction 1
Production 2
Geographic distribution of pecan trees 2
Location of pecan-producing districts 2
Production of pecans 4
Number of pecan trees 8
Ages of improved pecan trees 9
Trend of future production 10
Principal varieties of pecans 10
Size of pecan holdings 11
Trend in pecan plantings as indicated by census figures 12
Pecan condition reports and forecasts 12
Cost of production 14
Explanation of items 15
Farms studied 16
Planting distances of pecan trees 19
Control measures for pecan scab infestation 20
Control measures for pecan insects 22
Yield of pecans 23
Cost of developing pecan orchards and cost of operating bearing orchards, by districts 26
Marketing 62
Shipping-point practices 63
Shipping-point prices 65
Distribution of the 1928 improved crop 67
City market survey 69
Chain-store and consumer survey by mailed questionnaires 78
The shelling industry 85
Competition of pecans with other nuts 85
Summary 87

TECHNICAL BULLETIN No. 325.—BIOLOGY AND CONTROL OF THE BLACK VINE WEEVIL (Floyd F. Smith):

Introduction 1
Economic importance 2
Distribution 4
Host plants 4
Synonymy 6
Habits and descriptions of the stages 7
The egg 7
The larva 7
The prepupa 12
The pupa 12
The adult 14
Seasonal-history studies 21
Seasonal history out of doors 22
Seasonal history in the greenhouse 26
Natural enemies 33
Control 34
Preventive measures for greenhouse practice 34
Remedial measures 35
Summary 40
Literature cited 42

TECHNICAL BULLETIN No. 325 SEPTEMBER, 1932

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

BIOLOGY AND CONTROL OF THE BLACK VINE WEEVIL [1]

By FLOYD F. SMITH, *Entomologist, Division of Truck Crop and Garden Insects, Bureau of Entomology* [2]

CONTENTS

	Page		Page
Introduction	1	Seasonal-history studies	21
Economic importance	2	Seasonal history out of doors	22
Distribution	4	Seasonal history in the greenhouse	26
Host plants	4	Natural enemies	33
Synonymy	6	Control	36
Habits and descriptions of the stages	7	Preventive measures for greenhouse practice	34
The egg	7	Remedial measures	35
The larva	7	Summary	40
The prepupa	12	Literature cited	42
The pupa	12		
The adult	14		

INTRODUCTION

The first record of injury to cultivated plants due to the depredations of the larvae and adults of *Brachyrhinus sulcatus* was made in Germany in 1834 (*4, p. 201.*) [3] Since that time the weevil has been recorded with increasing frequency as causing injury to economic plants not only in continental Europe, England, and Ireland, but also in the United States, Canada, and Australia. Riley (*40*), in 1871, recorded the first economic damage in North America. A rather extensive list of plants has now been reported as being attacked in the field and in greenhouses.

Life-history studies of *B. sulcatus* under field conditions have been made in Europe (*15, 51*), and also in a general way in the United States. Its life history in the greenhouse, however, has received no previous detailed study so far as available publications indicate, except a preliminary report in 1927 (*44*) and another in 1930 (*45*) by the present author.

Infestations in the nurseries and greenhouses near Philadelphia, Pa., offered an opportunity for a study of the species which was taken

[1] *Brachyrhinus sulcatus* Fab., order Coleoptera, family Curculionidae.

[2] The author is indebted to C. H. Hadley, T. L. Guyton, C. A. Weigel, and Herbert Osborn for direction and counsel during the course of the work herein reported. H. J. Fisher assisted in the laboratory studies. Dorothy K. Smith assisted in the experimental work and in the preparation of the manuscript. The early part of the laboratory work was done in a laboratory at Willow Grove, Pa., maintained by the Bureau of Entomology in cooperation with the Bureau of Plant Industry of Pennsylvania.

[3] Italic numbers in parentheses refer to Literature Cited, p. 42.

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up as a project of the Pennsylvania Bureau of Plant Industry at its Willow Grove laboratory in collaboration with the Bureau of Entomology, of the United States Department of Agriculture. From October, 1925, until the spring of 1929 the life history of the species was followed both in the nursery and in the greenhouse, and methods of control in both were investigated. The morphology of the larva and adult has been worked out, but the data covering this phase of the investigation are reserved for a separate publication.

ECONOMIC IMPORTANCE

The black vine weevil was recognized as an economic pest of greenhouse plants in Germany as early as 1834 (*4*).

In England Westwood (*55*) in 1837 described the injury to Sedums and other plants in greenhouses; in 1875 Bolton (*3*) first recorded injury to grapes; and in 1881 Ormerod (*37, p. 361*) found that this weevil injured strawberries and raspberries.

Although Harris (*25, p. 49*) recorded this insect under the name *Curculio apiculatus* as occurring in Massachusetts as early as 1835, Riley (*40*), in 1871, was the first to mention the species as being injurious in North America. In 1890 Hagen (*24*) described a rather severe infestation in greenhouse cyclamens, and since that time many notes on the occurrence of injury to various greenhouse and outdoor-grown plants, both in North America and in Europe, have been published.

In many private greenhouses and conservatories in Pennsylvania, in each of which from 200 to 300 plants, principally cyclamen, are grown, the writer has observed from 1 to 70 plants to have been destroyed by the larvae. In commercial greenhouses the losses are greater.

The relation between cultural practices and recurring annual infestations are brought out by the following examples: (1) A florist at Norristown, Pa., experienced his first loss of cyclamens in 1923, and the injury almost doubled each year until the fall of 1927, when about one-third of his crop of 3,000 plants was destroyed; a florist in Scranton, Pa., has lost 200 cyclamens each year since 1924 from an annual crop of 1,000 plants. At both places few food plants of *B. sulcatus* were present outdoors, but each year the soil from the injured cyclamens was dumped on the compost pile located near the greenhouses. Here the larvae developed to adults, the latter returning to the greenhouses to renew the infestations. (2) For about eight years a florist near Philadelphia experienced an annual loss of from 150 to 200 out of about 1,000 cyclamens. Adjoining his greenhouses is an old cemetery in which are growing yews and rhododendrons, and a number of weed host plants. Apparently the adults entered the greenhouse each summer to oviposit after having developed outside. (3) Another florist in the same vicinity has lost from 75 to 300 cyclamen plants annually for the last 15 years. Here selected plants from the main crops are retained for seed production, and young seedlings for the next crop are grown in the same house. In two different years larvae, the offspring of adults from seed plants, have killed a number of the young plants during the summer. This damage has not been counted in the above-mentioned losses of the crop in the fall.

Probably the greatest losses have occurred on the island of Oléron off the west coast of France (*15*). This infestation increased from an area involving a few grapevines in 1909 to cover 150 acres and involve injury to 300,000 vines in 1914. The adults caused the most concern because of their feeding upon the buds, foliage, and young fruit and their girdling of the shoots. More serious injury, though less evident, was that of the larvae in girdling the roots. Vines so attacked lost vitality and died within a few years. Feytaud (*15*) also mentioned other less serious infestations on grapes in Germany, Switzerland, Italy, and Belgium. Thiem (*51, p. 390*) described the destruction in Germany in 1920 of 4,000 young grafted grapevines which was caused by the larvae girdling the roots.

Britton (*5, p. 230*) recorded considerable losses of yews in Connecticut, and Weiss (*54*) mentioned damage to yew and rhododendron in a New Jersey nursery. In 1926 the writer observed damage amounting to about $500 to yews at the same nursery. In Pennsylvania the black vine weevil has been well distributed on host plants in nurseries. In only one nursery, however, located near Philadelphia, has serious damage been observed, and there the foliage of yew, rhododendron, azalea, and euonymus was rather badly eaten by the adults. Roots of yews were injured by the feeding of the larvae. Yews and azaleas have also been damaged in certain California nurseries.

Strawberries have been frequently mentioned as being seriously injured by *Brachyrhinus sulcatus*, but Treherne (*52*) indicates that, although probably present in almost every strawberry-growing district, it does no serious harm. He believes that at least some of the previous reports have referred to *B. ovatus* which often seriously injures strawberries. Experiments at Willow Grove, Pa., with various hosts tend to bear out this point. Adults of *B. sulcatus*, when given a choice, fed almost entirely on primroses (*Primula* spp.), cyclamens, or dock (*Rumex* spp.) and very little on strawberry, and when confined on strawberry deposited fewer eggs than others caged on more favored hosts. The larvae, also, avoided the strawberry roots when those of other named plants were available, but when they were forced to feed on strawberry roots, their development was retarded, their mortality increased, and their bodies took on a reddish tinge. There was less accumulation of fat in larvae reared on strawberry than in those reared on primroses, cyclamens, dock, or yew.

Infestations occurring in greenhouses are more regular in their appearance each year and in the amount of damage caused than those under outdoor conditions. In the nurseries under observation infestations decreased in years following seasons of heavy rains during July and August and increased following years when there was less rain during these months. The greatest losses, both in North America and in Europe, have been to crops growing in loose types of soil.

From the foregoing it is evident that *B. sulcatus*, while rather sporadic in its occurrence, has caused very severe damage in several countries. The injury caused by it, while important to individual nurserymen and florists, probably does not greatly affect the total crop of any of its hosts. It is generally considered that the damage done by this weevil to cyclamens under glass is exceeded only by that of the cyclamen mite (*Tarsonemus pallidus* Banks).

DISTRIBUTION

Brachyrhinus sulcatus has been recorded from the following countries: Russia, Norway, Sweden, the Netherlands, Belgium, Germany, Austria, Switzerland, Italy (State of Tyrol and island of Sicily), France (including the island of Oléron, located northwest of Bordeaux on the west coast), England, Scotland, Ireland, Australia, Tasmania, and New Zealand. In the United States the insect has been recorded from the following States: Maine, Massachusetts, Connecticut, New York, Pennsylvania, New Jersey, Illinois, Missouri, California, Oregon, and Washington. Infestations have also been recorded from Newfoundland, Cape Breton Island, Nova Scotia, Quebec, Ontario, British Columbia, and Victoria Island.

Britton (*5*), among others, speaks of *B. sulcatus* as being of European origin. Frequent interceptions of this insect have been made in shipments of imported plants. Leconte and Horn (*31, p. 60*) stated that this was a European species which became distributed over the western continent naturally instead of by commerce. Schwarz (*43*) considered *B. sulcatus* as belonging to the circumpolar fauna and not as an imported species.

HOST PLANTS

The following list of host plants of *Brachyrhinus sulcatus* includes 52 previously reported in literature and 25 (indicated by *a*) found as new hosts in the present studies. The feeding of the adults was confirmed by the writer in these studies on the plants prefixed with *b*, and on those prefixed with *c* the larval feeding was confirmed. In general, Standardized Plant Names (*1*) and Gray's Manual of Botany (*23*) were followed in the nomenclature, with revisions by the Bureau of Plant Industry, United States Department of Agriculture.

b, c. Adiantum cuneatum (delta maidenhair).
b, c. Adiantum tenerum (fan maidenhair).
Ampelopsis sp.
b. Amygdalus persica (peach).
b. Asparagus plumosus (fern asparagus).
b. Astilbe rosea (rose astilbe).
Atriplex hortensis (garden orach).
Azalea spp.[4]
a, b, c. Azalea amoena (amoena azalea).
a, b, c. Azalea hinodegiri (Hinodegiri azalea).
a, b, c. Azalea indica hybrids (indica azalea).
b, c. Begonia spp. (begonia).
Beta vulgaris (beet).
Beta vulgaris (mangel wurzel).
a, b, c. Callistemma chinensis (China-aster).
Camellia japonica (camellia). (Reported by D. C. Mote in correspondence).
Cattleya sp. (orchid).
Cheiranthus cheiri (wallflower).
Citrus limonia (lemon).
b, c. Convallaria majalis (lily-of-the-valley).
b, c. Cyclamen indicum, variety (*C. gigantium*) (cyclamen).
Dracaena sp.
a, b, c. Euonymus americanus (brook euonymus).
a, b, c. Euonymus bungeanus (winterberry euonymus).

[4] In many previous reports of host plants in literature only the common names were given. In the present studies the attempt has been made to identify them by species. Therefore the number previously reported can not be clearly distinguished from the species here given.

a, b, c. *Fagelia*, hort. variety (*Calceolaria veitchii*) (Veitch calceolaria).
Fragaria spp. (strawberries).
b, c. *Fragaria* sp. (varieties Joe and Chesapeake).
Grossularia sp. (gooseberry).
b. *Howea belmoreana* (Belmore palm).[4]
b. *Howea forsteriana* (Forster palm).
Humulus lupulus (hop).
Hydrangea sp.
a, b, c. *Hydrangea opuloides* (hydrangea).
a, b, c. *Impatiens sultani* (sultan snapweed).
a, b, c. *Isoloma bogotense* (isoloma).
b, c. *Kalmia latifolia* (mountain-laurel).
Kraunhia floribunda (*Wisteria floribunda*) (wisteria).
a, b, c. *Leontodon officinale* (*Taxaracum officinale*) (dandelion).
Lewisia spp.
b. *Malus sylvestris* (apple).
Nephrolepis exaltata bostoniensis (Boston fern).[4]
a, b, c. *Nephrolepis*, varieties Scott and Verona.
a, b, c. *Oxalis acetosella* (woodsorrel).
a, b, c. *Oxalis enneaphylla rosea* (rosy nineleaf oxalis).
Oxycoccos macrocarpus (cranberry).
Pelargonium spp. (geranium).
Phaseolus vulgaris (bean).
Phyllitis scolopendrium (hartstongue).
Pisum sativum (pea).
a, b, c. *Plantago major* (rippleseed plantain).
a, b, c. *Plantago lanceolata* (buckhorn plantain).
a, b, c. *Polystichum acrostichoides* (Christmas fern).
a, b, c. *Potentilla canadensis* (common cinquefoil).
b, c. *Primula malacoides* (fairy primrose).
b, c. *Primula obconica*, variety (rosy top primrose).
b, c. *Primula praenitens* (*P. sinensis*) (Chinese primrose).
Prunus sp. (plum).
a, b, c. *Rheum rhaponticum* (rhubarb).
Rhododendron spp. (rhododendrons).[4]
b, c. *Rhododendron catawbiense* (Catawba rhododendron).
b, c. *Rhododendron* hybrids.
b, c. *Rhododendron maximum* (rosebay rhododendron).
Ribes spp. (currant).
a, b, c. *Rochea* (*Crassula*) *coccinea* (scarlet rochea).
b, c. *Rubus allegheniensis* (blackberry).
b. *Rubus idaeus* (European raspberry).[4]
b. *Rubus strigosus* (red raspberry).
b. *Rubus occidentalis* variety Cumberland (common blackcap).
a, b, c. *Rumex acetosella* (sheep sorrel).
a, b, c. *Rumex crispus* (curly dock).
a, b, c. *Rumex obtusifolius* (bitter dock).
Saxifraga burseriana and var. (saxifrages).
b, c. *Sedum acre* (goldmoss).
b. *Senecio cruentus* hybrids (cineraria).
Sinningia speciosa (gloxinia).
b, c. *Taxus cuspidata* and varieties (yew.)
Thuja occidentalis ericoides (heath retinispora).
b. *Thuja orientalis pyramidalis* (arborvitae)
b, c. *Tradescantia fluminensis* (wandering-jew).
Trollius sp.
Tsuga canadensis (hemlock).
a, b. *Viburnum dentatum* (arrowwood).
Viburnum prunifolium (blackhaw).
Vitis vinifera varieties (European grape, varieties).
a, b, c. *Zantedeschia aethiopica* (calla).
a, b, c. *Zantedeschia elliottiana* (golden calla).
Zea mays (corn).

[4] In many previous reports of host plants in literature only the common names were given. In the present studies the attempt has been made to identify them by species. Therefore the number previously reported can not be clearly distinguished from the species here given.

This extensive host list of *B. sulcatus* suggests the possibility that many additional plants might be favorable hosts.

Fletcher (*17, p. 242*) among others has suggested that *Brachyrhinus sulcatus* was primarily a grass-feeding species. To test this possibility, larvae were put in pots of quackgrass (*Agropyron repens*), Kentucky bluegrass (*Poa praiensis*), and orchard grass (*Dactylis glomerata*). They fed to a slight extent upon the tips of the underground stems of quackgrass and Kentucky bluegrass, which were softer and more succulent than the root parts, and in a similar way on the tender shoots of orchard grass before these emerged from the soil. Buckhorn plantain (*Plantago lanceolata*) and yarrow (*Achillea millefolium*) were fed upon to some extent about the crown. On red clover (*Trifolium pratense*) the nodules and softer cortex on the roots and crown were eaten to a moderate extent. No feeding was observed on alsike clover (*T. hybridum*), yellow biennial sweetclover (*Melilotus officinalis*), or alfalfa (*Medicago sativa*).

From these tests it is concluded that since no larvae could be reared to maturity on any of these hosts, none of them are of importance as hosts of the black vine weevil. Such plants, however, as dandelion, rippleseed plantain, and sorrel and dock (*Rumex* spp.) generally grow in grasslands and could readily supply food for the weevils found in such situations.

Although palms and geraniums have been recorded as host plants, the tests made by the writer with the Belmore palm, Forster palm, geraniums, and pelargoniums seemed to indicate that they were not favored hosts. When forced by hunger the adults fed slightly on the foliage and, although the larvae fed slightly on the roots, all died within three or four weeks, and none was reared to maturity when they were placed in pots containing these plants.

SYNONYMY

Fabricius (*11, p. 485*), in 1792, described the weevil *Curculio sulcatus* as follows: "Brevirostris femoribus dentatis ater elytris striatus ferrugineo maculatis." The type locality was given as Saxony. In 1804 Latreille (*28, p. 157*) erected the genus Brachyrhinus and placed *sulcatus* in it. In 1824 Germar (*19*) erected the genus Otiorhynchus, giving characters similar to those used by Latreille and placed many of the same species in it. It appears that Germar was unaware of Latreille's work. Schoenherr (*42, v. 2, pt. 1, p. 620*), in his monograph of Curculionidae, listed previous literature but omitted the work of Latreille. Later, in 1843, Schoenherr (*42, v. 7, pt. 1, p. 371*) placed Latreille's Brachyrhinus in synonymy under Otiorhynchus of Germar. Nearly all of the European publications appearing since that time have used the generic term Otiorhynchus, and most American authors did likewise until Leng (*32, p. 314*) corrected the error by placing Otiorhynchus as a synonym of Brachyrhinus.

In the present paper Brachyrhinus is used uniformly for each species mentioned, whether the author cited had used Otiorhynchus or Brachyrhinus as the generic name.

HABITS AND DESCRIPTIONS OF STAGES

THE EGG

The egg, which is generally subspherical, ranges in length from 0.65 to 0.80 mm on the long axis and from 0.65 to 0.70 mm on the short axis. When first laid, the egg is a uniformly glistening, pearly white, and its smooth, unsculptured surface reflects light as a mirror. The shell is resilient and rather tough, and the side of the egg may be pressed in without rupturing it. When the egg is forced into a crevice by the ovipositing female it becomes flattened or wedge shaped, but this does not interfere with the hatching.

In from 1 to 3 days, depending upon the temperature, the egg changes during a period of about 12 hours through a grayish yellow to a chestnut brown, the color being uniform throughout, and the egg and shell becoming more rigid. In from 8 to 10 days about one-fourth of the egg becomes still darker, and in this area the head of the larva develops. The mandibles, and then the head sclerites and labrum, take form and color and may be distinguished about 3 days before hatching.

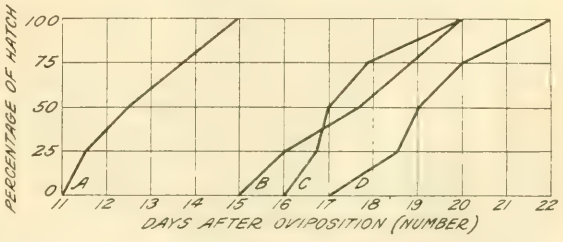

FIGURE 1.—Hatching of *Brachyrhinus sulcatus* at Willow Grove, Pa. Lot A, 317 eggs, at soil temperature of 78°–82° F., greenhouse, August, 1928; lot B, 140 eggs, at soil temperature of 58°–68°, greenhouse, May, 1926; lot C, 838 eggs, at soil temperature of 59°–64°, outdoors, September, 1928; lot D, 126 eggs, at soil temperature of 57°–62°, greenhouse, February, 1928

In the process of hatching the mandibles open and close rhythmically and the shell is cut or torn about one-third of the way around the side. The mandibles, followed by the remainder of the head, are forced through the opening, and the body is then drawn out of the shell. After the emergence of the larva the shell collapses somewhat, appears chitinous, and is dark brown.

The darkening of the egg shortly after it is laid is probably due to color changes in the shell rather than in the interior. A few eggs from nearly every observed lot failed to darken, but became grayish and decomposed after from 15 to 20 days. The percentage of eggs failing to develop was much larger at lower temperatures. In the nursery 92 per cent of the eggs observed during July and August hatched. Figure 1 indicates the variations in the length of the incubation period, which ranged from 11 to 22 days, in the greenhouse and nursery during different seasons of the year.

THE LARVA

The width of the head capsule of the various larval instars is indicated in Table 1. The head of the newly hatched larva is chestnut brown, and the rather prominent mandibles are darker brown. The body is pinkish white and sufficiently transparent to show the stomach through the wall. The body is covered with small hairs, as is that of the mature larva.

TABLE 1.—*Measurements in each instar of width of head capsules of reared larvae of Brachyrhinus sulcatus, Willow Grove, Pa., 1928*

Instar	Group A, 9 larvae with 7 instars			Group B, 19 larvae with 6 instars		
	Mode	Maximum	Minimum	Mode	Maximum	Minimum
	Mm	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*
First	0.318	0.318	0.318	0.318	0.318	0.318
Second	.403	.445	.381	.403	.445	.403
Third	.551	.615	.551	.615	.636	.55
Fourth	[1]	.805	.636	[1]	.89	.678
Fifth	[1]	1.06	.848	1.06	1.06	.91
Sixth	1.27	1.27	1.06	1.5	1.5	1.31
Seventh	1.48	1.44	1.64			

[1] The mode is given only when more than half of the larvae in the group have the same width of head capsule.

The young larva crawls about actively. Its body is not curved It attempts to enter the soil at once, but if the surface is hard or packed it will fail in this, and in such a case death occurs in a few hours. Even firmly pressed sand seems to be penetrated with difficulty, and clay or loam unless covered with mulch or in a loose, well-cultivated condition, seems to be almost impenetrable. The hardness of the soil seems to be a controlling factor in the degree of infestation, the more severe infestations occurring in the lighter types of soil. This bears out the observations of Downes (*10*) on injury by *Brachyrhinus ovatus* to strawberries in British Columbia. Injury by *B. sulcatus* to yews in Connecticut (as described by W. E. Britton in correspondence with the author) and to grape in France (*15*) seem related also to the type of soil. In potted plants entrance into the soil is generally made either at the edge of the pot or between the roots at the base of the plant.

Thiem (*51*) stated that the larvae can subsist on manure or on decaying vegetable matter and probably are transported in this material. Feytaud (*15*) believed that for the first few weeks the larvae developed on organic matter in the upper soil layers until the grape roots were reached farther down. In the various tests the writer found that few larvae were able to develop to the second instar in potting soil devoid of all living plant roots but containing leaf mold and well-rotted cow manure. In two tests only 3 larvae out of 100 reached the second instar; these then died. When rootlets of food plants were present, however, the larvae attacked these, and as many as 80 per cent of the larvae matured.

In several tests in the laboratory dried stems which had become moistened by contact with the soil, or green foliage and stems of host plants, have served as food for larvae in all instars.

As the larva increases in size in each instar the body becomes curved by the thickening of the thoracic segments, and the head appears small in proportion to the remainder of the body. When ready to molt, the larva stops feeding and forms a cell, preferably in a piece of heavier clay or hard piece of dung, which may be present in the soil. The interior of the cell is smooth-walled, and apparently the larva uses the contents of the alimentary tract to make it so. Evidence of this trait is further indicated by the fact that larvae handled at cell-forming time will eject watery fecal matter, and this has not been observed with larvae at other stages of growth.

After a quiescent period of from one to three days or longer in the cell the head capsule and thoracic segments split along the median dorsal line. The head of the larva is then pushed through the opening, and the old skin is gradually worked off backward by frequent alternating waves of expansion and contraction of the body progressing forward from the posterior end. The old skin is afterward found in a much-wrinkled condition at the bottom of the cell. It was observed that the entire process of molting required 55 minutes in one individual at the fifth molt and about two and one-half hours in another larva at the third molt. At first the head of the freshly molted larva is milky white, only the tips of the mandibles being dark brown. From one to three days are spent in the cell after molting, and the head capsule becomes brownish and quite firm. The larva then breaks out of the cell and returns to the roots of the food plant. The periods of molting, especially the first three, seem to be the most critical stages in the life of the growing larva. Many die in the resting stage before molting; others die while emerging from the old skin.

FIGURE 2.—A plant of fairy primrose (*Primula malacoides*) whose fine rootlets have been eaten by a young larva of *Brachyrhinus sulcatus* which may be seen below the base of the plant ball. Willow Grove, Pa., 1928. × 0.5

Until the third molt the larva confines its feeding to the small rootlets (fig. 2), but with the beginning of the fourth instar the larva begins to attack the larger roots. On such plants as cyclamen or primrose the soft fleshy roots are cut off within a short distance of the crown or corm and may or may not be devoured. If a large number of larvae are present, the stumps of the roots are then eaten and the corm or crown gouged or hollowed out. (Figs. 3, 4, and 5.) The feeding during the last two instars is rapid, and the infested plant may exhibit no injury until the sudden wilting due to the cutting of the roots occurs. The young larva feeds on the young rootlets of woody plants such as yew (*5*) or grape (*15*), but in later instars it feeds on the cortex of the larger roots. The root may be entirely stripped of its bark for several inches, girdled at one or more points, or only gouged out on one side.

Root cutting and gouging out the corm of certain plants furnish an abundance of material for building up the body preparatory to pupation. Larvae which had not eaten off the plant roots were not reared to the adult stage so successfully as were those (in other pots) which had eaten off the roots. This habit evidently serves also as a protection to the larva in the cell, for examination showed that many cells of the former had been penetrated by the roots and the larvae had died in each instance.

Wilson (*56*) describes the tunnelling or boring habits of certain specimens of *B. rugifrons* Gyll. into the stems and leaf petioles of Saxifrages. The writer has frequently observed that *B. sulcatus* larvae tunnel out the crown and the bases of the larger petioles of primroses aboveground. Larvae attacking roots of dock usually feed on the cortex outside the woody cylinder, but sometimes they tunnel along the pithy area in the center of the root. In two observed cases, heavily infested cyclamen plants with large corms became honeycombed with larval tunnels. Larvae in less heavily infested pots ate off only part of the roots before finishing their growth. The burrowing habit of *sulcatus* larvae does not seem to be an inherited or racial characteristic with this species as suggested for *rugifrons* by Wilson, but rather it is followed where food is deficient.

FIGURE 3.—Two cyclamen plants, the one on the left destroyed by root-cutting larvae of *Brachyrhinus sulcatus*. Willow Grove, Pa., 1928. × 0.3

Feytaud (*15*) states that a part of the larvae complete their feeding in vineyards in the fall and that they form cells from 15 to 40 centimeters below the surface and there spend the winter. In the spring these larvae break out of their cells and come nearer the surface, where they form the pupal cells. During the fall of 1927 the author placed about 100 larvae in the prepupal stage in artificial cells (½ by 2 inch glass cylinders) and buried these at depths ranging from 6 to 24 inches. In the following spring, at the normal time for pupation, the cylinders were examined, and the insects had pupated in the overwintering cells without first approaching the surface. From these observations the writer is inclined to believe that Feytaud mistook the larvae in the fifth or sixth instar in their overwintering cells for larvae in prepupal cells. In Pennsylvania the immature larvae were observed to form overwintering cells at varying depths down to 18 inches but usually from 6 to 8 inches below the surface. These had voided the gut contents and appeared quite like the prepupae in all respects except for

size. Mature larvae in prepupal cells were found at no greater depths than 4 or 5 inches. Apparently the larvae rarely if ever leave the prepupal cells to form new ones unless disturbed, as by plowing.

In the nursery, the infested plants do not occur in a definite area but are scattered at random. At Rutherford, N. J., in 1926, about 25 yew plants were severly injured, and with two exceptions each of these plants was located between unaffected plants. Diggings revealed from 18 to 24 larvae about the base of each injured plant and from none to 4 about thrifty ones. The root systems of these heavily infested plants were considerably nearer the surface than were those of the uninfested ones. In Pennsylvania, the weevil was more abundant in well-fed and mulched blocks of yew than in those receiving little care. In the latter case the roots were deeper in the soil which was devoid of surface organic matter,

FIGURE 4.—Cyclamens and primroses (*Primula malacoides*): The roots of the center plants have been destroyed by larvae of *Brachyrhinus sulcatus*. The outside plants are uninfested. Willow Grove, Pa., 1927

whereas in the former the roots approached the surface and were more easily reached by the young larvae through the loose surface material.

The mature larva is slightly pinkish white, the food material in the alimentary tract adding other color. If the larva feeds on species of Rumex (sorrel or curly dock), the body has a decided yellowish tinge; if on strawberry, it has a reddish tinge. With the formation of the pupal cell the gut contents are completely voided, and the body is then milky white. It seems certain that the material in the intestine is utilized in moistening the soil and in developing the smooth and hardened walls of the cell. The larva lies in a half coiled position supported by its dorsum against one side of the chamber and the tip of the abdomen against the other, about half way between the upper and lower ends of the cell. The prepupal stage has been observed to be as short as three weeks or as long as eight and one-half months, depending upon the soil temperature.

THE PUPAL CELL

The cells (fig. 6) for pupation are formed rather near the surface, usually within 1 or 2 inches, but with extremes of one-half and 6 inches. Unless the soil is rather sandy and crumbly, the cell wall becomes quite firm and is one-sixteenth to one-eighth inch thick. The fine soil particles apparently intermixed with the gut contents of the

larva form a puddled layer which grades off into the surrounding soil with no definite line of demarkation. The cell wall is not entirely impervious to water. The cell is considerably larger in both length and breadth than its occupant at any stage of development. The pupa is usually located toward the upper end of the chamber. Table 2 gives the size of several pupal cells, their depth in the soil, and the size of the emerging adults.

TABLE 2.—*Summary of measurements of the pupal cells of Brachyrhinus sulcatus, their depth in the soil, and the length of the emerged adult, Willow Grove, Pa., 1927*

No.	Depth of cell in soil	Inside measurements of cell		Length of emerged adult	No.	Depth of cell in soil	Inside measurements of cell		Length of emerged adult
		Diameter	Length				Diameter	Length	
	Inches	*Mm*	*Mm*	*Mm*		*Inches*	*Mm*	*Mm*	*Mm*
1	1¼	6	13	10	5	¾	8	14	11
2	1⅛	7	14	11	6	2¼	7	14	11
3	⅞	6	14	11	7	½	8	15	11
4	1	7	14.5	11					

FIGURE 5.—Root of curly dock (*Rumex crispus*) which has been gouged out by larvae of *Brachyrhinus sulcatus*, Willow Grove, Pa., 1928. × 0.3

THE PREPUPA

After the formation of the cell at the conclusion of the larval feeding period, the milky-white larva with a glistening chestnut-brown head capsule remains quiescent until pupation. At the beginning of this stage the larva will almost always form a new cell if the original one is broken. As development progresses and the time for pupation approaches, the larva becomes less active and may then be readily placed in an artificial cell for observation.

The body gradually changes to a muddy-yellow color, and the head becomes a weathered brown. Then the thoracic segments enlarge slightly on the dorsal side, and the prothorax and head of the pupa take form there. The larval skin splits along the median line of the thorax and of the head capsule and is worked off posteriorly. The shedding of the larval skin after it splits required 40 minutes in one case and from 60 to 80 minutes in three other observed instances.

THE PUPA

At first the pupa is entirely milky white with rather conspicuous dusky spines definitely arranged on the head, femora, and abdomen. The head is bent beneath the body and lies on the breast. The mandibles are provided with curved hooks which give the mouth parts an overbalanced appearance. The spines seem to be used as hooks in maintaining the position in the upper part of the cell. The pupa can

move by the bending of the abdomen in any direction. In this manner the pupa is able to turn its body around in the cell when exposed to light or when the cell is broken.

In an individual which spends the maximum time in the pupal stage, the eyes turn brown and then black in the course of the first 8 or 10 days. By this time the striae in the wing pads become evident. About five days before the change to adult the mandibles become a rusty brown; and during the next two days they become black, and the rusty color extends to the eyes on the snout. At this time the antennae, tarsi, and femoral tips also become a rusty brown, which deepens just previous to the shedding of the pupal skin. The legs darken at the joints, the snout becomes black to the eyes, the prothorax faintly rusty, the occiput, elytral pads, and abdomen creamy white. With a shorter pupal period all of these changes are

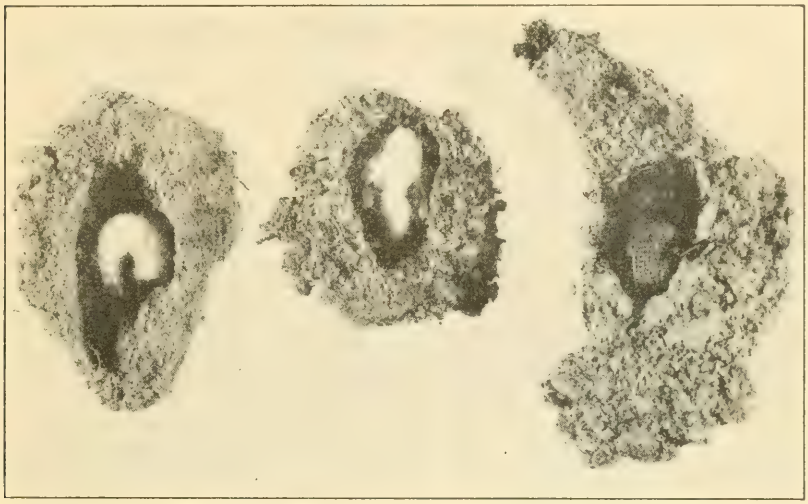

FIGURE 6.—Cells of *Brachyrhinus sulcatus* with one side removed showing respectively, from left to right, a prepupa, pupa, and an unemerged adult. Willow Grove, Pa., 1928. × 2

correspondingly accelerated. In the change to adult the thin-walled pupal skin splits along the median dorsal line on the prothorax and occiput and is worked off posteriorly. The whole procedure in one individual has not been accurately timed, but in several cases it required less than two hours.

The length of the pupal period of 77 *Brachyrhinus sulcatus* in the greenhouse at Willow Grove, Pa., from January to March, 1928, when the soil temperature ranged from 57° to 68° F., during the observations was as follows:

Number of individuals:	Length of stage (days)	Number of individuals—Con.	Length of stage (days)
2	15	8	20
14	16	3	21
21	17	3	22
15	18		
11	19	Average	17.91

THE ADULT

Blatchley and Leng (*2, p. 111*) describe the adult (fig. 7) of *Brachyrhinus sulcatus* as follows:

> Oblong, brownish-black, subopaque. Thorax subcylindrical, not longer than wide, its surface densely covered with rounded tubercles, each bearing a short hair. Elytra oblong-oval, striae coarsely punctured and with remote patches of yellowish hair; intervals feebly convex, each with a row of shining rounded tubercles. Femora strongly club-shaped, deeply sinuate near tip. Length 8.5 mm.

The adults mentioned by these writers are smaller than are most of the present writer's specimens. A few adults, such as those reared from larvae pupating in the fifth instar, were only 8.5 mm in length, but most living adults measured from 10.5 to 11.5 mm. When recently emerged, the adult is glistening black with irregularly placed tufts of yellowish hairs on the elytra which gives the body a dull appearance. The elytra have no articulation at the base, but the whole is thickened chitin. The two are usually said to be fused along the median line, but in dissection they readily separate after being cut off at the base. The hind wings are reduced to small pads which lie on either side beneath the elytra. The eyes are black, and the head is smoother than the thorax and has a thin covering of short pubescence. The antennae are shining black and slightly pubescent, which gives them a brownish tinge. The legs are black, with the tibiae and tarsi thickly covered with a brown pubescence. The exoskeleton is pliable and easily broken at this time.

FIGURE 7.—The black vine weevil (*Brachyrhinus sulcatus*): Adult. × 4

The body of the newly transformed adult is milky white, except for the snout and eyes, which are black, the antennae, coxae, femoral tips, tibiae, and tarsi, which are rusty brown; and the prothorax, which is faintly rusty. Within an hour after transformation the elytra expand to cover the abdomen and meet along the median line. On the following day the general body color becomes a dark chestnut brown with the abdomen yellowish brown ventrally. Three days after transformation the body is a glistening black except for the brownish antennae and tarsi. By the fourth or fifth day after transformation the patches of yellowish hair on the elytra become evident, and the adult is apparently ready to emerge.

The adult is seemingly very weak after transformation, but gradually gains strength and, in a few days, responds more quickly when disturbed. In most cases the adult breaks out of the cell and digs its way to near the surface by means of its deciduous mandibular ap-

pendages. The earth is torn into fine particles by means of these appendages, worked past the body, and lodged in the cell cavity as the adult moves into the excavation. With but few exceptions in many observed cases,[5] the adult, during the night in which the cell is broken, continues its digging toward the surface until only a thin crust remains. On the following night, usually in the early evening, the adult completes the act of emergence and goes into hiding without feeding. This differs from the habit of *B. ovatus*, which emerges soon after transformation (*52*), and then remains in hiding without feeding for several days until the body darkens and hardens.

The period from transformation to emergence of 141 adults of *Brachyrhinus sulcatus* in the greenhouse at Willow Grove, January to April, 1928, when the soil temperature varied from 59° to 70° F. during the observations was as follows:

Number of individuals:	Number of days in stage	Number of individuals—Con.	Number of days in stage
1	4	15	10
6	5	3	11
14	6	2	12
28	7	1	15
51	8	1	17
19	9		
		Average	8.03

After the adults have been hiding beneath clods of earth in the fields the striae often become filled with soil, and the whole elytral surface becomes coated with mud. Adults which seclude themselves among leaves or trash or under bark become dull gray as a result of dust accumulation. Sometimes they acquire a thin incrustation of greenish algae. The original shining black also weathers and fades as the adult ages, and the exoskeleton becomes greatly thickened and very hard.

Feeding by *B. sulcatus* begins on the night after emergence. On thick cyclamen leaves small rounded notches are bitten from the edge, whereas on thin cyclamen and primrose leaves, or on flower petals, the areas eaten are sickle shaped and much larger. (Figs. 8 and 9.)

The adult prefers cyclamen flowers to the leaves, but this preference is less evident with primrose. The pinnae of ferns are notched, bitten off, and either allowed to fall to the ground or eaten entirely. Rhubarb, dock, sorrel, plantain, and other plants are badly notched or eaten out between the veins. Yew needles are bitten off at the tip, notched along one side, or eaten completely. The foliage toward the interior is more severely attacked than that on the terminal growth. (Figs. 10 and 11.)

Many new growths are girdled late in the season by the removal of a narrow ring of bark at the base. These twigs die during the following winter, and often the plant is then mistakenly said to be "winterkilled." As many as 30 per cent of the twigs on some plants

[5] The procedure by which the adult broke the cell and dug toward the soil surface by aid of the mandibular pieces was readily observed through the glass sides of the artificial cells in which the prepupae had been placed for observation of their development. These deciduous mandibular pieces were usually lost between the completion of their approach to the surface and the breaking through of the crust. Some individuals retained one or both appendages for a few days after emergence. One individual emerging naturally and several others removed from their cells before starting to emerge retained these pieces for over two months. Apparently these adults fed without inconvenience. In all observed cases each deciduous appendage was shed in one piece. Several apparently normal adults died after breaking their cells. These individuals were found to have lost these pieces, which loss probably accounted for their failure to reach the surface.

have been found girdled in this manner. Leaf petioles and flower stems of such plants as cyclamen, primrose, or strawberry are notched, often so deeply that the stem breaks at the point of injury. (Fig. 10.) Feytaud (*15*) described the girdling of the new growths year after year on grape, and the throwing out of new branches below the point of injury. An injured plant develops a witch's-broom effect. The buds and foliage are also devoured, and the young grapes are cut from the stems.

The female feeds most extensively during the preoviposition period, less during the egg-laying period, and still less during the period between the close of oviposition and the beginning of hibernation.

It is generally reported that the adult hides during the day beneath pieces of earth, stones, sticks, dried grass, or leaves in the vineyard or strawberry field (*15*, *51*, *54*). The writer has observed the adults

FIGURE 8.—Typical feeding by *Brachyrhinus sulcatus* on a thick leaf (left) and on a larger, more tender cyclamen leaf (right). Willow Grove, Pa., 1927

behaving in this manner in the nursery when the yew and rhododendron plants were small, but where larger plants were infested the beetles were found on the trunks beneath the loose bark or among accumulations of needles lodged in the forks of the branches (*44*). This was especially noticeable in 1926 at Chestnut Hill, Pa., where in one day 127 beetles were collected from beneath the loose bark and from lodged needles on seven yew trees while none were found among the trash on the ground. This season was very rainy, and observations made at night, together with the ineffectiveness of baits spread to attract the insects to the ground, indicated that the beetles did not move from tree to tree or come down to the ground to any extent. The adult avoids moisture and will not hide in wet trash on the ground. If the small wad of fibrous orchid peat supplied to caged individuals as a hiding place became wetted during watering the beetles avoided their haunt and spent the day in the top of the cage. The arboreal habit of the adults in the nursery may be due, in part, to the moist condition of the trash on the ground.

The adults were abundant in 1926, but the rainy period was accompanied by a high mortality of the weevil before oviposition began. On July 26, 1926, in a block of small yew 284 dead adults and only 56 live ones were collected about the plants. This point may be one factor in the reduction of the infestation in 1927 following a period of abundant rainfall preceding and during the oviposition period, for the insects were scarce in 1927. As there was little rainy weather during July and August of that year they were more numerous in 1928, when again there was little rainfall in the same period. The larvae were rather numerous in the fall of 1928, and adults were correspondingly abundant in 1929.

To compare the oviposition rate in dry and rainy weather, two lots of adults were collected from the field and each lot divided into two equal parts and caged on primroses. For 10 consecutive evenings, cage 1 of each group was sprinkled so that the foliage remained moist during the night while the other cages were kept dry. The 17 individuals in the two wetted cages laid a total of 120 eggs during the 10 nights while the same number of adults in the dry cages laid a total of 715 eggs. The amount of feeding was also reduced in the wetted cages.

FIGURE 9.—Normal cyclamen bloom (left) and a bloom showing feeding by *Brachyrhinus sulcatus*. Willow Grove, Pa., 1927

Chips, sphagnum, straw, or excelsior laid about on the ground have been recommended by Thiem (*51*), Weiss (*54*), and others for catching the adults which hide in the material. Such traps have proved to be of little value in the greenhouses when tested by several florists. As cyclamens, the usual host plant in Pennsylvania, are sprinkled several times daily during the summer to keep down the temperature and the rate of evaporation the trap materials become wetted and are unattractive to the adult in search of a hiding place. The usual hiding place in the greenhouse is on the side of the pot just below the projecting edge of its thickened rim, or among the leaf petioles on a many-leaved plant. The adult's preference for the better protection supplied by the more numerous stems, where more of the eggs are likely to be laid, may explain the usually greater damage by the larvae to the best plants in a lot.

Downes (*10, p. 8*) described the migratory habit of the wingless weevils of *Brachyrhinus ovatus* at the period just before egg laying begins and again at the close of this period as the adults are in search of hibernating quarters. Downes, working with *ovatus* and Feytaud (*15*) and Thiem (*51*) with *sulcatus* observed the gradual spreading of the weevils from a common center or from adjacent fields. The present writer has not had the opportunity to observe the migration of *sulcatus* in the nursery, but the weevils seem to drift into the greenhouses throughout the egg-laying season, as indicated by nightly collections made by florists.

About the close of the oviposition period the weevils apparently leave the greenhouse to hibernate out of doors, this being indicated by a cessation of feeding. During four years' study no feeding on foliage or flowers has been observed in commercial greenhouses between the middle of September and the emergence of the next generation of adults in midwinter.

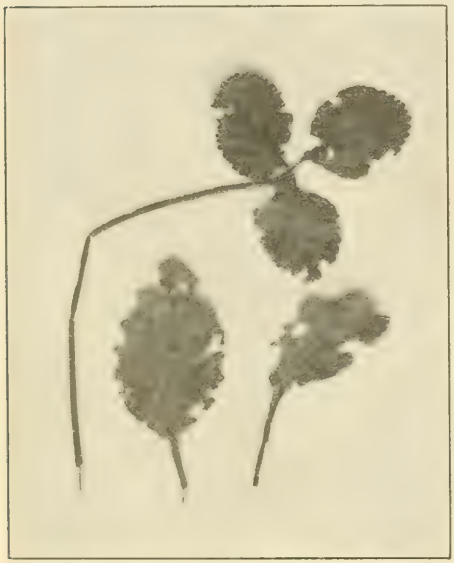

FIGURE 10.—Feeding of adults of *Brachyrhinus sulcatus* on strawberry (left) and on ripppleseed plantain (*Plantago major*). Willow Grove, Pa., 1928

When adults are being handled a drop of dark-green liquid, probably regurgitated food, often appears on the mouth parts. The fecal matter is dry for the most part and falls to the ground, but sometimes it is soft, adheres to the foliage, and there serves as a medium for fungous growth.

OVIPOSITION

Puls (*38*), who observed adult *B. sulcatus* on grapes in greenhouses in Belgium, described the act of oviposition. He stated that the female, resting on a vine branch, simply dropped the eggs singly; and as no glutinous material covered the outside, they came to rest on the ground. Feytaud (*15*) agreed with Puls and also noted eggs in soil interstices.

In the nursery the writer has found the eggs on the ground, in trash or among soil particles, lodged beneath loose bark, or between needles of yew plants as high as 3 feet from the ground. In the greenhouse they were found on the soil surface and on the leaves and stems of such hairy plants as primrose; also in hollows or clefts in stems and corms, or inserted about 1 mm into soil crevices. In the latter situation the eggs are often so flattened or wedge shaped that it seems that they were forced into these places.

The writer has observed the act of oviposition by caged females at night. Without any preliminary actions, the anal segment is lowered and the ovipositor is extended about 1½ mm. The egg is then forced down the egg tube and dropped. Adults have been seen

dropping eggs while resting on the side of the cage, on the foliage, and on the ground. The ovipositor was never seen inserted in a soil crevice or other cleft, but it seems that this is probably what takes place when eggs are found in such situations.

LONGEVITY OF ADULTS UNDER VARIOUS ABNORMAL CONDITIONS

Forty adults collected in the nursery July 29, 1926, were confined in salve boxes without food or water. Twenty-one lived for 10 days; 11 for 11 days; and 8 for 12 days. The weevils appeared normal the day preceding death. Weevils collected on September 24, 1926, lived 8 days in salve boxes without food or water. In March, 1928, a number of adults (Table 3) were confined as soon as they emerged,

FIGURE 11.—Feeding of adults of *Brachyrhinus sulcatus* on rhododendron (left), *Euonymus americanus* (upper right), and *Taxus cuspidata*. Chestnut Hill, Pa., 1928

(1) in watch glasses without food or water, (2) in cages on bare soil but watered daily, and (3) in cages on soil with dried cyclamen leaves as food and watered daily. In lot 3, the adults fed freely on the dried cyclamen leaves. This would indicate that the adults may subsist on areas devoid of green crops until they can migrate to adjacent areas where food plants are being grown. The adults in this test laid no eggs, and examination at death showed the reproductive organs to be undeveloped and the viscera emaciated. From Table 3 it will be seen that the weevils in lot 2 lived the longest on an average.

TABLE 3.—*Longevity of adults of Brachyrhinus sulcatus confined under abnormal conditions in greenhouse at Willow Grove, Pa., 1928*

Lot No.	Condition under which kept	Adults in test	Number of adults dying at age of—								Average age at death
			10 days	11 days	13 days	16 days	21 days	27 days	34 days	40 days	82 days	
		Number										*Days*
1	Without food or moisture	18	3		4		7		4			20.3
2	On moist soil	22				5		6		11		31.0
3	Dried leaves and water supplied	22	6	6			4			3	3	26.2

PARTHENOGENESIS

The first record of parthenogenetic reproduction in the genus Brachyrhinus was made by Ssilantjew (*46*), in 1905, in his studies with the species *turca* Boheman. He dissected over 1,000 adults during the season without finding a male and also gathered over 100,000 adults in the field without observing a single pair in copula. He also found that all of 30 adults, isolated before emergence, laid fertile eggs from which larvae developed and matured normally. He contrasted the lack of copulation of *turca* in the field with the frequent pairing observed between the two sexes of *B. asphaltinus* Herm., an associated species on the grape. *B. ligustici* Fab. (*53*), *B. cribricollis* Gyll. (*22*), *B. ovatus* L. (*9, p. 86*), and *B. rugifrons* Gyll. (*56*) were proved, by methods of isolation similar to Ssilantjew's, to reproduce parthenogenetically. The writers reporting on these species found no males in their studies.

Feytaud (*14*), during three years' study of *B. sulcatus*, examined thousands of individuals externally and dissected over 3,000 without finding a male. He collected 100 adults soon after they had emerged, half of which, when dissected, showed no spermatozoa in the seminal receptacles. The other half of the collection was reared through the summer and produced fertile eggs, and later dissection showed that all were females. Feytaud failed to isolate individual pupae or recently transformed adults before emergence, as had been done with the other species, but stated that if any copulation had taken place in the 4 to 5 day interval between emergence and collection of these adults, spermatozoa would have been evident in the receptacles of the first lot.

During the writer's studies on *B. sulcatus* six generations of isolated adults have been found to reproduce parthenogenetically. In all cases the individuals were isolated in the prepupal stage, and the adults were kept in individual, double-walled, screen cages until found to produce fertile eggs. In two generations larvae were isolated at the time of hatching and kept from others throughout their immature and adult life. Between 1,100 and 1,200 individuals taken in the field or in the greenhouse, or reared from either situation, have been dissected and found to be females. This work reinforces the observations of Feytaud and agrees with the studies made by other workers on the reproduction of five other species of Brachyrhinus. A seventh species, *B. asphaltinus* (*46*), has been shown to reproduce sexually and to possess males. Various workers state that their particular species is "irregularly parthenogenetic" (*14, 22*) and that males may occur sporadically in certain generations. Stierlin (*47, p. 226*) described the elytra of the male *sulcatus* as narrower than those of

the female, with the underside of the insect obsoletely impressed, and the anal segment subfoveolate. Reitter (*39*) suggested that *linearis* Stierlin is the male of *sulcatus* and is distinguished from the female by the longitudinal strigae on the second to fourth sternites and by the feeble impression on the anal sternite. Since *linearis* has been found only in Italy, where it is abundant, and Reitter admits having seen his "male *sulcatus*" from no other place whereas the female is widespread, L. L. Buchanan, of the Bureau of Entomology, considers this sufficient grounds to doubt the suggestion of Reitter. In the writer's life-history studies smaller and more slender adults have been reared from larvae which entered the prepupal stage an instar earlier than normal as a result of a lack of food or of unfavorable food. These adults answered Stierlin's description of the male of *sulcatus*, but the dissection or rearing of these proved them to be females.

SEASONAL-HISTORY STUDIES

Since *Brachyrhinus sulcatus* is a pest on both greenhouse and outdoor-grown plants, it was to be expected that its seasonal life history would be quite different in the two situations. A 3-year study of the life history under each condition was made, and the relationship between the greenhouse and outside infestations was established.

Adults were confined, either singly or in groups of three to nine individuals, in cylindrical screen cages 9 inches high and 4 inches in diameter placed over host plants growing in 4-inch pots. The eggs, as laid, were placed on soil in short tubes with plaster of Paris bottoms. These tubes were corked at hatching time. The larvae on emerging were transferred to the desired food plants, usually from 10 to 15 to a plant in a 4-inch pot. Isolated larvae were reared in 1-ounce salve boxes containing well-decomposed leaf mold and supplied daily, while young, with fine rootlets and later with larger roots and plant crowns. Table 4 gives data on the length and number of instars of two groups of isolated larvae in the greenhouse.

TABLE 4.—*Summary of length of instars of isolated larvae of Brachyrhinus sulcatus reared in the greenhouse, Willow Grove, Pa., 1928*

Instar	Group A, 9 larvae with 7 instars			Group B, 19 larvae with 6 instars			Summary of both groups		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
First	14.62	21	11	14.68	20	10	14.66	21	10
Second	14.12	31	8	10.52	14	8	11.59	31	8
Third	14.82	20	12	12.73	22	10	13.33	22	10
Fourth	14.0	18	10	12.52	19	10	12.96	19	10
Fifth	13.62	18	10	16.84	32	11	15.88	32	10
Sixth	15.62	20	12	15.0	21	14	15.81	21	12
Seventh	12.37	17	12						
Total length of individual development	98.6	113	92	86.4	109	79	90	113	79

The larvae in the soil of potted plants were readily transferred to new hosts. The time of completion of feeding and of the formation of prepupal cells was therefore easily determined. Until the time for pupation approaches, the larva is easily disturbed and forms a new cell if the original one is opened. To observe pupation, transformation to adult, and emergence of adult, artificial cells were made by

pushing a cylindrical stick, of a diameter equal to a normal pupal cell, down one side of a soil-filled glass cylinder one-half inch in diameter and 2 inches in length. The larva in late prepupal stage was then taken from its natural cell in the soil, lowered into the artificial cell, and the hole closed above the larva. The cylinder was then placed in the soil, the top even with the surface. Each numbered larva was then observable through the glass by drawing the cylinder from the soil, the cylinder being replaced after each observation. These larvae developed normally as compared with those which formed their own cells against a glass plate placed in the soil. When the adult was about to emerge, a glass shell vial was inverted over the cylinder, and in this way isolated virgins were obtained.

The life-history studies of the adult outdoors were conducted in an insectary, and studies of the larvae and pupae were made in open beds. The greenhouse bench furnished normal conditions for indoor studies.

SEASONAL HISTORY OUT OF DOORS

Brachyrhinus sulcatus may pass the winter in the larval, prepupal, or adult stage. During five winters' observation in Pennsylvania, from 1924 to 1929, adults were found to pass the winter only in 1924–25 and 1926–27, and then only in small numbers. Of 700 adults placed in hibernation cages during the years 1926–1928, only one emerged the following spring to oviposit the second season. The majority of the individuals hibernated as prepupae or as nearly grown larvae. Seventy-five per cent of the individuals observed in 1925–26 passed the winter as prepupae; 25 per cent in 1926–27; and 95 per cent in 1927–28. The late, warm fall of 1927 permitted later feeding of larvae, thus a larger number reached maturity before being overtaken by cold weather. The immature larvae generally pass the winter in the fifth or sixth instar, but a few may be in the fourth.

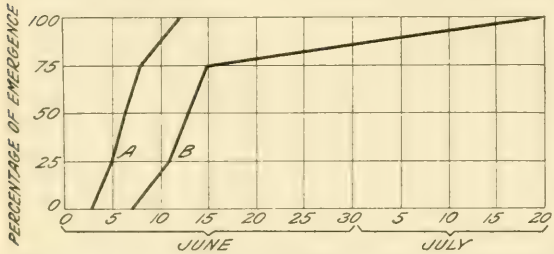

FIGURE 12.—Emergence of adults of *Brachyrhinus sulcatus* in 1927 at Willow Grove, Pa.: A, 47 adults emerged from compost heap; B, 229 adults emerged from collections made in nursery April 20 to June 18

Thiem (*51*), among others, stated that the winter may be passed as pupae or as unemerged adults within the pupal cells. To test this possibility the writer, on February 1, 1928, placed 60 pupae and 38 unemerged adults in cells out of doors in soil below the frost line. By March 16 all of the adults had died within the cells, and two weeks later all of the pupae were dead. One hundred prepupae put out at the same time survived the winter and emerged as adults the following June. No pupae or unemerged adults have been found by the writer in the nursery during the winter. The above test indicates that winter conditions are less favorable for these stages of the insect than for the prepupae or immature larvae.

The immature larvae became active early in the spring, when the soil temperature was 42° F. (Observed March 1, 1928.) The larger

ones completed growth during April, passed through a short prepupal stage, and pupated with the overwintering prepupae. Pupation began about May 10 in 1927 and 1928 as the soil temperature rose above 55° F. The pupal stage lasted about 22 days, and the adults transformed early in June and emerged from 7 to 8 days later, usually about June 10 to 20, as shown in Figure 12 for 1927.

The smaller overwintering larvae completed their growth later in the spring, even as late as June. Some emerged as late as July 20.

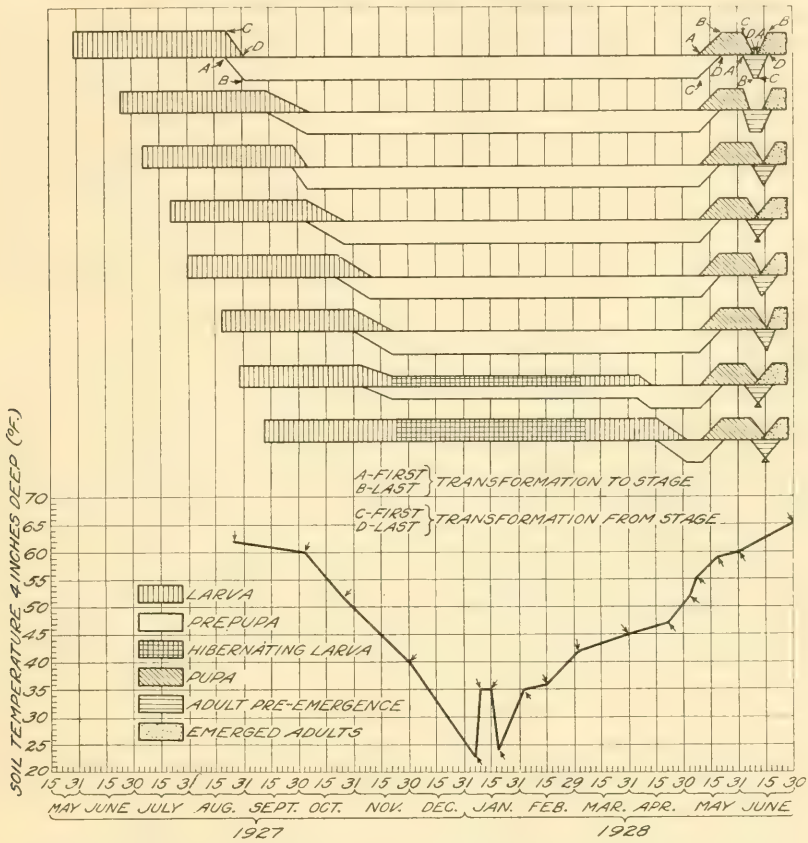

FIGURE 13.—Development of eight lots of *Brachyrhinus sulcatus* outdoors from time of hatching at known dates during the egg-laying season of 1927. Below is given a curve showing the soil temperatures on the dates indicated by darts. Willow Grove, Pa.

Usually, however, most of these late-maturing larvae died in the prepupal stage. No larvae were observed by the writer to hibernate a second winter in Pennsylvania, though a slightly shorter season might make this possible. This was shown by the fact that larvae which were reared so that they reached maturity late in August, 1927, did not produce adults until the following spring. (Fig. 13 and Table 5.)

TABLE 5.—*Summary of development of Brachyrhinus sulcatus under outdoor conditions from time of hatching at known dates throughout the egg-laying season of 1927, Willow Grove, Pa.*

Lot No.[1]	Larvae hatched	Cells were formed	Pupation	Emergence	Cells were formed	Pupation	Transformation	Emergence	Adults emerged
	1927	*1927*	*1927*	*1927*	*1928*	*1928*	*1928*	*1928*	*Number*
1	May 31	Aug. 20–Sept. 1	Oct. 6[2]	Nov. 16[3]		May 10–21	June 5–10	June 12–16	18
2	June 24	Sept. 13–Oct. 6	0	0		do	June 8–12	June 15–18	27
3	July 7	Sept. 28–Oct. 6	0	0		do	June 9–14	June 15–20	35
4	July 21	Oct. 5–26	0	0		do	June 5–12	June 13–18	27
5	Aug. 1	Oct. 21–Nov. 10	0	0		do	June 8–16	June 14–22	37
6	Aug. 19	Nov. 1–21	0	0		do	June 10–14	June 16–22	34
7	Aug. 29	Nov. 4–21[4]	0	0	Apr. 6–16[5]	do	June 6–12	June 10–19	68
8	Sept. 12		0	0	Apr. 16–May 2	May 10–23	June 8–15	June 14–22	58

[1] 200 larvae were put out in each of the 8 lots.
[2] 1 larva pupated.
[3] 1 adult emerged.
[4] 68 per cent of larvae formed cells.
[5] 32 per cent of larvae formed cells.

The few overwintering adults emerge from hibernation early in May (May 4, 1925, May 7, 1927), begin to oviposit late in May (May 22, 1927), and continue to do so until September. One adult, depositing 41 eggs in 1926, produced 822 eggs during 1927. One adult, captured May 18, 1927, laid 135 eggs before her death, July 20, 1927. During the period of these studies only three adults were found to hibernate successfully outdoors and to deposit eggs a second season. In Pennsylvania, then, hibernation in the adult stage appears to be quite exceptional.

The main adult emergence extended from June 10 to July 20 during three years' observations, the peak occurring about the middle of June. (Fig. 12.) Several writers (*5*, *15*, *18*, *51*) stated that adults of *B. sulcatus* emerged in April and May. Emergence is very likely dependent upon the soil temperature, as illustrated by the following example in the spring of 1928. A quantity of larva-infested soil had been dumped outside earlier in the winter between the greenhouse and a thick hedge in a place fully exposed to the sun during the day and protected from the winds at night; thus the soil temperature here during April was considerably higher than that in the open. Adults here began emerging on May 3, at a soil temperature of 60° F., or 8° higher than soil at the same depth in the open, where they did not emerge until a month later.

In the 3-year study the first eggs were laid July 17 to 20 by the June-emerging adults. The preoviposition period was from 28 to 50 days. The average number of eggs laid per day by one adult was 13, with a range of from 0 to 27. The individual fecundity seemed to vary considerably as between individuals in different seasons on the same host plants, and between individuals on different host plants. A study of Tables 6 and 7 will show these points. The average number of eggs laid by adults confined to different host plants is especially interesting. Highest averages of oviposition rates were obtained from adults feeding on fairy primroses, although adults on rippleseed plantain produced nearly as many per individual. Adults confined to yew, strawberry, and curly dock produced only about half as many eggs, and adults on Boston fern produced very few.

TABLE 6.—*Oviposition records of Brachyrhinus sulcatus out of doors at Willow Grove, Pa., 1926–1928*

Season of—	Individuals under observation	Host upon which adults were confined	Preoviposition period			Eggs laid			
			Maximum	Minimum	Average	Total	Maximum	Minimum	Average
	Number		*Days*	*Days*	*Days*	*Number*	*Number*	*Number*	*Number*
1926	[1] 4	*Primula malacoides*	49	32	44.7	1,717	863	284	429.25
	[2] 2	*Nephrolepis* sp.	54		54	9	9	0	4.5
1927	[3] 6	*Fragaria* sp.	49	35	45.5	231	131	0	38.5
	[4] 10	*P. malacoides*	45	35	38.7	1,633	401	40	204.1
	[5] 26	*P. malacoides*				5,717			219.9
1928	9	*P. malacoides*	45	38	42.4	3,589	488	129	398.8
	[6] 4	*Rumex crispus*	47	33	40.6	437	176	0	109.2
	4	*Taxus cuspidata*	56	37	44.7	573	278	46	143.2
	[7] 6	*Fragaria* sp.	36	36	36	1,351		0	225.1
	[8] 3	*Plantago major*			33	738			246.0

[1] 1 adult laid 41 eggs in 1926 and 822 eggs in 1927.
[2] 1 adult lived 52 days, then died without laying eggs; this is a greater age than the average length of preoviposition period.
[3] 2 adults died without ovipositing after living 59 days and 38 days, respectively. Considered in the average of oviposition records.
[4] 2 adults died at ages of 24 and 25 days, respectively. Not considered in average or minimum of oviposition records.
[5] Adults collected in nursery before egg laying began and confined in 5 cages.
[6] 1 adult died at age of 97 days without ovipositing. Considered in average for oviposition.
[7] 1 adult lived 83 days without ovipositing. Considered in average for oviposition.
[8] Adults confined in 1 cage.

TABLE 7.—*Summary of oviposition records of Brachyrhinus sulcatus out of doors, according to host plant used, Willow Grove, Pa., 1926–1928*

Host plant	Adults observed	Adults not ovipositing	Eggs laid	Individual egg records		
				Maximum	Minimum	Average
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Primula malacoides [1]	49	2	12,656	488	40	269.27
Plantago major	3	0	738			246.0
Taxus cuspidata	4	0	573	278	46	143.25
Fragaria sp.	12	[2] 3	1,582	293	0	131.83
Rumex crispus	4	[2] 1	437	176	0	109.25
Nephrolepis sp.	2	[2] 1	9	9	0	4.5
Summary	74	7	15,995	488	0	216.14

[1] The adult depositing 863 eggs in two seasons was not considered in the column of maximum individual oviposition.

[2] See footnotes, Table 6. These adults lived longer than the normal preoviposition period and are included in computing the average oviposition.

The larvae hatching from the first eggs laid in late May by overwintering adults entered the prepupal cells in late August or early September. A few of these pupated and emerged as adults during the same fall, but most of them lay in their cells until the following May. Larvae hatching at later periods throughout the egg-laying season completed maturity later in the fall or, if overtaken by cold weather, in the early spring. (Table 5 and Fig. 13.) The developmental period of the larvae was observed to be as short as 74 days and as long as 7½ months, and the prepupal period lasted a minimum of 21 days and a maximum of 8½ months. This variation is apparently due to the soil temperature. The larvae were observed to feed at soil temperatures of 42° F., but none was observed to pupate at soil temperatures below 55°. This habit permits the later hatching larvae in each season to complete growth late in the fall and early in the spring and then to pupate and emerge as adults with the overwintering prepupae developing from early laid eggs.

In Pennsylvania there is, then, one brood of adults annually under field conditions. The few adults, however, which hibernate successfully and oviposit a second summer cause an overlapping of generations. The observations on the experimental life-history studies were frequently checked with natural infestations in nurseries where collections were made and reared.

SEASONAL HISTORY IN THE GREENHOUSE

Studies of the life-history of *Brachyrhinus sulcatus* in the greenhouse were planned to determine whether infestations continued from year to year independent of any outside infestations and, if so, whether the usual greenhouse practices influence the infestations and the life history of the insect.

Observations in commercial greenhouses and in the laboratory show that the larvae mature for the most part from late October to early December. In the cooler greenhouses where a high temperature is not kept for forcing a Christmas crop, some larvae may not mature until early in March, but this is exceptional. As the larvae complete their feeding by cutting off the roots, the affected host plants sud-

denly wilt, turn yellow, and die at the time for marketing the crop. If these injured plants are allowed to remain on the bench or are thrown beneath it, in the rush to make room for the next crop, the larvae pupate, and adults emerge from late in January to early in April, the majority in February. If such host plants as cyclamen seedlings or ferns are accessible the adults feed on these and begin laying eggs from 50 to 70 days after emergence. The first eggs are usually laid in April or early in May, and the larvae hatching from them will mature in August. During the early summer months the cyclamen plants are often too small to furnish sufficient food for the larvae in the pot, and both plant and insect die.

In many observed cases, however, the thrifty florist threw the infested soil from his unsalable cyclamens on the compost heap near the greenhouse for later use. The larvae in this soil, having completed their feeding and formed prepupal cells in the greenhouse, lay dormant until spring and then emerged as adults in June—about the same time as those developing entirely outdoors. This point was checked by placing larva-infested soil on a compost heap in November and recording the emergence of adults the following June. (Figs. 12 and 13.) These summer-emerging adults, from the compost heap or from outdoor hosts, migrate into the greenhouse and feed and oviposit from the middle of July to early in September. Larvae hatching from their eggs mature in the fall and early winter. (Table 8.)

The temperature of the soil in the greenhouse affects the development of this insect just as does the temperature outside. During the cloudy months, from the latter part of October through the early part of January (in the vicinity of Philadelphia), the soil temperature ranged from 48° to 51° F. in several greenhouses, then rose from 7° to 10° with the coming of more sunny days. Pupation began with this rise in temperature. The adults which emerged early in the spring in the greenhouse also continued to oviposit throughout the spring and summer.

TABLE 8.—*Summary of data on development of 578 adults of Brachyrhinus sulcatus in the greenhouse during 1926–27 (A) and 1927–28 (B) at Willow Grove, Pa.*

Lot No.	Date eggs were laid	Date eggs hatched	Date larvae matured	Date of pupation	Date of transformation to adult	Date adult emerged	Period for development
	1926	*1926*	*1926*	*1927*	*1927*	*1927*	*Days*
A1	May 19–24	June 5–10	Sept. 12–18	Feb. 2–18	Feb. 18–Mar. 9	Feb. 18–Mar. 16	270–301
A2	July 8–10	July 23–25	Oct. 15–25	Feb. 9–16	Mar. 8–14	Mar. 14–21	247–256
A3	July 28–31	Aug. 15–18	Nov. 14–25	Jan. 29–Feb. 11	Feb. 19–Mar. 10	Mar. 2–17	214–232
A4	Aug. 15–23	Aug. 29–Sept. 6	Nov. 25–Dec. 5	Feb. 9–Mar. 8	Mar. 3–28	Mar. 12–Apr. 8	201–236
A5	Aug. 23–Sept. 4	Sept. 6–8	Dec. 5–24	Jan. 31–Feb. 28	Feb. 23–Mar. 21	Mar. 4–29	181–218
A6	Sept. 11–19	Sept. 26–Oct. 4	Dec. 15–Jan. 31	Feb. 4–Mar. 1	Feb. 28–Mar. 26	Mar. 9–Apr. 3	171–204
		1927	*1927*	*1927*	*1927*	*1927*	
B1		May 4	Aug. 1–12	Aug. 28–Sept. 2	Sept. 21–29	Oct. 2–10	[1] 151–159
				1928	*1928*	*1928*	
B2		June 12	Aug. 27–Sept. 2	Jan. 4–6	Feb. 1–7	Feb. 11–14	[1] 283–286
B3		July 20	Oct. 5–27	Jan. 15–Feb. 5	Feb. 11–27	Feb. 19–Mar. 6	[1] 252–268
B4		Aug. 13–19	Nov. 6–Dec. 19	Jan. 17–Feb. 2	Feb. 12–25	Feb. 20–Mar. 5	[1] 215–229
B5		Sept. 15–19	Dec. 10–Jan. 5	Jan. 20–Feb. 5	Feb. 13–26	Feb. 21–Mar. 5	[1] 186–205
			1928	Jan. 31–Mar. 6	Feb. 19–Mar. 22	Feb. 28–Mar. 27	[1] 162–194
B6		Sept. 27–29	Jan. 10–Feb. 16	Jan. 28–Mar. 6	Feb. 18–Mar. 22	Mar. 4–29	[1] 157–184
B7		Oct. 13–20	Jan. 13–Feb. 16	Feb. 2–Mar. 3	Feb. 20–Mar. 4	Mar. 11–26	[1] 143–165

[1] Not including incubation period.

Adult feeding on the foliage stops suddenly in September, and it is evident that they normally seek hibernating quarters outside, where most of them die before spring. But in the laboratory tests the adults which otherwise would have migrated outside were kept in the greenhouse in cages on cyclamens or primroses until they died, and records were made of the number of eggs laid. (Table 9.) Egg laying stopped early in October, and the adults became very sluggish and ate little until December or January, when they became active again, ate voraciously, and then began again to oviposit. Oviposition continued, in most cases, until the early part of the next summer, though a few oviposited until September.

In Table 10 is given a summary of the longevity records of the groups shown in Table 9.

TABLE 9.—*Oviposition records of Brachyrhinus sulcatus in the greenhouse at Willow Grove, Pa., during the seasons 1926–1928*

GROUP A.—ADULTS DEVELOPING ENTIRELY IN THE GREENHOUSE

Season	Individuals observed	Date of emergence	Preoviposition period			Eggs laid first season			
			Maximum	Minimum	Average	Total	Maximum	Minimum	Average
	Number		*Days*	*Days*	*Days*	*Number*	*Number*	*Number*	*Number*
1926–27	5	February, 1926	78	58	66.2	3,981	1,083	466	796.2
	2	do	70	66	68	1,581	907	674	790.5
1927–28	9	February, 1927	80	54	64.7	7,643	1,055	568	849.2
	3	March, 1927	76	61	69	1,802	866	143	600.6
	[1] 26	do				14,758			567.6
Summary	45		80	54	66.1	29,765	1,083	143	661.4

Season	Eggs laid second season				Eggs laid both seasons by all adults			
	Total	Maximum	Minimum	Average	Total	Maximum	Minimum	Average
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1926–27	1,864	598	220	372.8	5,845	1,340	1,016	1,169
					1,581	907	674	790.5
1927–28	3,420	726	106	380	11,063	1,681	674	1,229.2
					1,802	866	143	600.6
	6,742			374.5	21,500			826.9
Summary	12,026	726	106	375.8	41,791	1,681	143	928.7

GROUP B.—ADULTS DEVELOPED IN THE FIELD, THEN CAGED IN THE GREENHOUSE

Season	Individuals observed	Date of emergence	Preoviposition period			Eggs laid first season			
			Maximum	Minimum	Average	Total	Maximum	Minimum	Average
1926–27	3	June, 1926	41	31	36	1,303	650	306	434.3
	1	do	40	40	40	67	67	67	67
	[2] 7					1,764			252
1927–28	7	June, 1927	37	28	33	2,117	538	170	302.4
	2	do	34		34	398	398	0	199
	[3] 25					5,677			227
Summary	45		41	28	34.4	11,326	650	0	251.7

[1] Of these adults, 8 died at the end of the first season and 18 of them oviposited the second season.
[2] These adults were collected in the nursery, June 25, 1926, and caged together.
[3] Of these adults which were collected in the nursery, June 25, 1927, 13 died at the end of the first season and 12 oviposited the second season.

TABLE 9.—*Oviposition records of Brachyrhinus sulcatus in the greenhouse at Willow Grove, Pa., during the seasons 1926–1928*—Continued

GROUP B.—ADULTS DEVELOPED IN THE FIELD, THEN CAGED IN THE GREENHOUSE—Continued

Season	Eggs laid second season				Eggs laid both seasons by all adults			
	Total	Maximum	Minimum	Average	Total	Maximum	Minimum	Average
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1926–27	1,984	813	478	661.3	3,287	1,160	999	1,095.3
					67	67	67	67
	2,769			395.5	4,533			647.6
1927–28	4,390	929	310	627.1	6,507	1,099	667	929.6
					398	398	0	199
	9,541			795.1	15,218			608.7
Summary	18,684	929	310	644.3	30,010	1,160	0	666.9

TABLE 10.—*Records of adult life of Brachyrhinus sulcatus in the greenhouse at Willow Grove, Pa., during the seasons 1926–1928*

GROUP A.—ADULTS DEVELOPED ENTIRELY IN THE GREENHOUSE

Season	Individuals observed	Date of emergence	Age of adults at death		
			Maximum	Minimum	Average
	Number		*Days*	*Days*	*Days*
1926–27	5	February, 1926	640	427	550
	2	do	257	169	213
1927–28	9	February, 1927	628	414	531
	3	March, 1927	254	164	223.6
	26	do	671	39	390.6
Summary	45		671	39	417.58

GROUP B.—ADULTS DEVELOPED IN THE FIELD, THEN CAGED IN THE GREENHOUSE

1926–27	3	June, 1926	504	344	423.6
	1	do			103
1927–28	7	June, 1927	470	281	378.7
	2	do	156	34	95
Summary	13		504	34	324.2

The adults emerging in the greenhouse early in the spring oviposited over a longer period and laid an average of 661.4 eggs, as compared with the average of 251.7 eggs laid by the adults emerging outside in June. During the second season the latter group deposited an average of 644.3 eggs, while the former averaged only 375.8 eggs per individual. However, the adults developing inside averaged 928.7 eggs, as compared with 666.9 eggs, the average laid by the other group. The greatest number of eggs laid by one individual was 1,681.

The cessation of egg laying and the state of inactivity assumed by the adults confined in the greenhouse at about the same time that the adults outdoors enter hibernation seem to indicate a seasonal cyclic

phenomenon independent of the temperature. The period of inactivity in the greenhouse, though short, is of such length that in the three years' study eggs were never laid in November, the only month of the year in which oviposition did not occur. In commercial greenhouses, the adults disappear in September, and none are present to deposit eggs until January, when adults emerge from the infested soil. It is thus shown that the adults may oviposit through two full seasons, both in the greenhouse and out of doors. Table 11 shows the life span of 10 individuals followed from the time the egg was laid to the death of the adult.

TABLE 11.—*Summary of life span of 10 isolated individuals of Brachyrhinus sulcatus in the greenhouse, Willow Grove, Pa., 1926–1928*

Individual No.	Egg was laid	Egg hatched	Larva matured	Pupation	Adult emerged	Adult died	Total life span
	1926	*1926*	*1926*	*1927*	*1927*		*Days*
G127	May 6	May 21	Aug. 28	Jan. 16	Feb. 18	July 31, 1928	817
G227	July 8	July 22	Nov. 5	Jan. 20	Feb. 23	Apr. 13, 1928	645
G327	July 28	Aug. 13	Nov. 14	Feb. 18	Mar. 2	Aug. 21, 1928	755
G427	do	Aug. 14	do	Feb. 1	do	Oct. 12, 1928	807
G527	Aug. 1	Aug. 16	Nov. 18	Jan. 28	Mar. 4	Mar. 9, 1928	586
G627	Aug. 15	Sept. 1	Dec. 5	Feb. 21	Mar. 28	Sept. 8, 1927	389
G727	July 28	Aug. 13	Nov. 18	Jan. 31	Mar. 6	Nov. 16, 1927	476
G927	do	Aug. 12	Nov. 14	Feb. 3	Mar. 9	Oct. 21, 1928	816
G1027	Aug. 1	Aug. 16	Nov. 25	do	Mar. 8	Nov. 16, 1927	472
G1227	July 28	Aug. 12	Nov. 14	Feb. 4	Mar. 10	June 13, 1928	686

Table 12 summarizes the development of *B. sulcatus* in the greenhouse during the spring and early summer of 1928. The larvae, as hatched, were placed in pots containing fairy primroses. As the plants declined from the effects of feeding, the insects were transferred to new uninfested plants. At the approach of maturity some of the larvae were examined every two days, and those which had completed feeding were transferred to soil in pots without plants, where they formed the pupal cells. Usually, these were not disturbed further until the time of pupation, a month later. Others were not examined at all, but records of adult emergence were kept. In this series one larva completed growth in 72 days, spent 21 days as a prepupa, 15 days as a pupa, and 8 days as an unemerged adult, a total developmental period of 116 days.

TABLE 12.—*Development of Brachyrhinus sulcatus in the greenhouse during 1928, Willow Grove, Pa.*

Lot No.	Eggs hatched	Cells were formed	Average period of larval development	Adults emerged	Average total period of development
			Days		*Days*
1	Jan. 27	Apr. 8–16	75	June 10–July 1	146
2	Feb. 9	Apr. 25–29	78	June 22–July 8	143
3	Feb. 24	May 9–16	79	June 19–July 9	131
4	Mar. 1	May 19–23	80.7	July 8–17	133
5	Mar. 20	May 31–June 5	74	July 14–18	117
Average			[1] 77.8		[2] 134.7
Maximum			82		155.0
Minimum			72		116.0

[1] Only 32 insects were examined for the period in this stage.
[2] For 48 adults.

During 1926 and 1927 attempts to rear the insects in the hot summer months through the prepupal and pupal stages to adults were unsuccessful, the larvae dying in the prepupal stage. The mortality in this stage exceeded 60 per cent in the summer of 1928, but the remainder were successfully reared, probably because they were not disturbed during this stage. Figure 14 shows the soil-temperature range correlated with the period of development of this series. From this figure it can be seen that an increase in the soil temperature little affected the development of the larvae, but shortened markedly the prepupal and pupal stages.

Although larvae were reared, as hatched, throughout the three seasons, the mortality of larvae maturing during the hot summer months was 100 per cent. (Table 13.) Larvae maturing late in

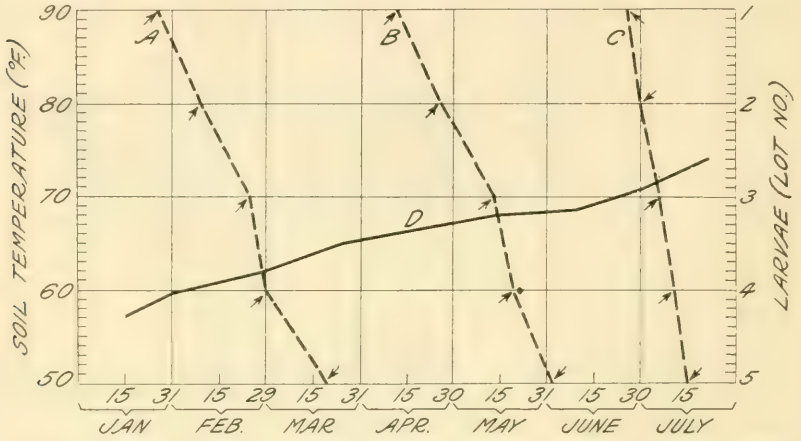

FIGURE 14.—The effect of soil temperature on the developmental stages of *Brachyrhinus sulcatus* at Willow Grove, Pa., 1928: A, Dates of hatching; B, dates of maturity; C, dates of emergence of the adults; D, temperature. The line A connects the records of hatching of five lots of larvae on January 25, February 9, 24, and 29, and March 18. These same larvae matured on April 12 and 26, May 13 and 19, and June 2, respectively, the practically constant distance apart of the lines A and B indicating that the larval period was not affected by the rise of the temperature. The space between the lines B and C, however, narrows considerably on approaching the records for lot 5, showing that the prepupal and pupal stages were shortened under the influence of the higher temperature experienced by that lot

August and during the remainder of the fall were successfully reared. It is evident that a cool soil is favorable to the insect in the prepupal stage.

TABLE 13.—*Comparison of mortality of larvae of Brachyrhinus sulcatus in the prepupal stage at various seasons, Willow Grove, Pa., 1926–1928*

Lot No.	Time of prepupal period	Average soil temperature during prepupal period	Larvae in prepupal cells	Adults emerged	Mortality in stage
		° *F.*	*Number*	*Number*	*Per cent*
1[1]	January–March	61	242	165	31.82
2[2]	do	61	208	186	10.58
3	Late June–August	82	348	0	100.0

[1] Placed in artificial cells.

[2] Not disturbed after forming cells.

NATURAL ENEMIES

Feytaud (*15*) stated that the mole ate both larvae and adults, of the black vine weevil, but as it inhabits damp places, while the weevil prefers sandy areas, it is of little value. The hedgehog, he said, eagerly devours the adult weevils; and its dung, found in the vineyards, was composed almost entirely of carapaces of this weevil. One night in July, 1928, the author observed a skunk searching about the bases of yews in a Philadelphia nursery where the adult weevils averaged from 10 to 12 on each plant. In an adjoining fence row near a skunk den was an accumulation of dung in which 147 carapaces, undoubtedly of *Brachyrhinus sulcatus*, were counted. The nest of a deer mouse (*Peromyscus leucopus*), found in a stone pile, in September, 1927, contained chewed portions of *sulcatus* and of May beetles, but it was not determined whether the insects were dead or living when eaten.

Among the bird enemies of *B. sulcatus*, Theobald (*50*) listed the titmouse, flycatcher, several warblers, finches, and starlings in Great Britain. Godard (*21*) listed the stone chatterers (Troquet), larks (*Alauda arborea* L.), and tufted lark (*Galerida cristata* L.) as particularly beneficial in the control of adults of *sulcatus* in the vineyards of France. Kalmbach and Gabrielson (*26*) found *sulcatus* among the weevils in the stomachs of starlings (*Sturnus vulgaris*) in the United States. Feytaud (*15*) found that poultry, especially turkeys, picked up many of the larvae exposed by plowing in the vineyards.

Various lizards (*Lacerta viridis* Gesn., *L. stirpium* Bon., and *Anguis fragilis* L.) were said by Feytaud (*15*) to be of value in the control of *B. sulcatus*. He also said that toads, especially *Bufo vulgaris*, were active about the vineyards. In July, 1928, the writer examined two toads near Philadelphia, Pa., whose stomachs contained seven and one adults of *sulcatus*, respectively.

Among the insects Feytaud (*15*) found carabid beetles, *Carabus auratus* L., *Feronia* sp., and *Poecilus* sp. attacking *B. sulcatus* larvae. The staphylinid beetle *Ocypus olens* Mull. was another enemy. The digging wasp *Cerceris arenaria* L. (*15*) stored her nest with adults of *sulcatus* after paralyzing them. *Blacus* sp., a braconid, is said to parasitize the adults (*13, p. 24*). Thiem (*51*) stated that a tachinid, *Pandelleia sexpunctata* Pand., parasitized larvae and adults in Germany. In the spring of 1928 carabid larvae in the writer's life-history plots and in the nursery were suspected of feeding on the larvae of *sulcatus*. Two of these larvae confined in pots of soil for 21 days, killed and partly ate 14 and 22 *sulcatus* larvae, respectively, in the third and fourth instars. These carabids were not reared to adults. In the laboratory an ant (*Formica* sp.) was seen to carry away many eggs and first-instar larvae of *sulcatus* to its nest, and once a second-instar larva was carried away. Feytaud (*15*) stated that *sulcatus* larvae were comparatively free of parasites. The present writer found no insect parasites of any of the stages in his studies.

Decaux (*8*) was unsuccessful in inoculating larvae of *Brachyrhinus* spp. with the fungi *Entomophthora plusiae* and *E. saccharina*. W. A. McCubbin, of the Pennsylvania Bureau of Plant Industry, found a species of Isaria in diseased larvae taken from Pennsylvania greenhouses. He believed that the fungus probably attacked only dead or

weakened larvae and that it was only slightly, if at all, parasitic. Larvae were also examined by Vera K. Charles, of the United States Bureau of Plant Industry, who found a species of Fusarium which she said might be parasitic. The writer has often observed prepupae and pupae of *B. sulcatus* which were dead in their cells covered either with a felted mass of hyphae or with white bands of hyphae extending out from the body in all directions among the soil particles. (Fig. 15.) Occasionally adults developing a similar fungus die before emergence. A larva which has had to construct a second cell is more subject to fungus attack than others.

The larvae maturing during the period of warmer soil temperatures (70° to 80° F.) die in much greater numbers than do those passing the prepupal stage with soil temperatures between 55° and 65° F. (Table 13.) It was not determined whether the fungi were more virulent at higher temperatures and killed the larvae, or whether the latter were so weakened under the warmer conditions that they fell an easy prey to these weakly parasitic fungi. At any rate this factor may have some bearing in the determination of the southern range of the species. With longer seasons maturity would be reached before the soil cools with the approach of fall, and as a result there would be high mortality in the prepupal stage.

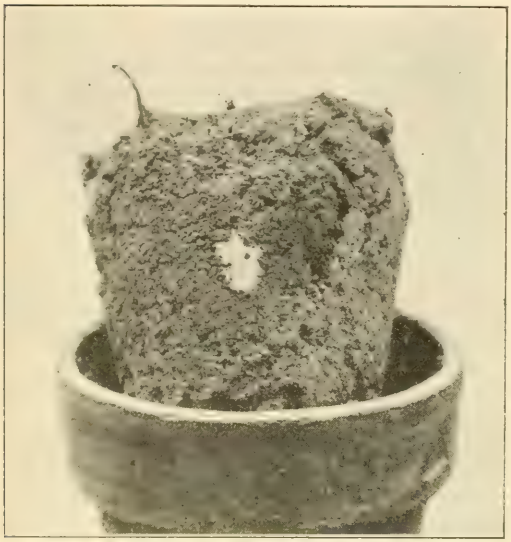

FIGURE 15.—A fungus, *Fusarium* sp. growing on a prepupa of *Brachyrhinus sulcatus*, Willow Grove, Pa., 1928. × 0.5

CONTROL

Many recommendations for control of the black vine weevil have evidently been made without a test of the methods or without a knowledge of the life history and habits of the insects. Recommendations, both preventive and remedial, based on the present studies, are here given.

PREVENTIVE MEASURES FOR GREENHOUSE PRACTICE

An understanding of the life history of the black vine weevil in greenhouses will readily indicate several points in general greenhouse practice which may be modified to reduce or eliminate this pest. (1) A thorough clean-up should be made of all host plants grown through the preceding summer before adults emerge in January or February. When this is not possible such plants should be separated from the younger plants to prevent an infestation in the next crop from the migrating weevils. The discarded plants, together with the soil infested with larvae, should not be allowed to remain on the compost heap or near the greenhouse, since adults would emerge from these

and return to the greenhouse to renew the infestation. (2) Soil that has once been infested should not be used again unless it has been sterilized by steam, or submerged under water for at least eight days. (3) Outdoor hosts should be either eliminated or treated to destroy the infestation. (4) Caution should be exercised in purchasing stock to bring into the greenhouse only uninfested plants.

BARRIERS, SCREENS, AND TRAPS

In the present studies, sticky barriers, as suggested by Felt (*12*), were placed on greenhouse benches in July and August and found to be crossed in some instances by the adults. The florists usually objected to the inconvenience of such a barrier.

On one estate, cyclamens grown during the summers in a coldframe situated near infested yews and rhododendrons, became infested each year until protected by a well-fitting screened frame constructed under the direction of the writer. This method is considered practicable only for protecting small numbers of plants.

The use of materials such as excelsior, orchid peat, and small pieces of board and broken pots on the benches as traps, frequently advocated, attracted very few adults in infested commercial greenhouses. The adults avoid damp or wet situations, and the frequent watering of plants during the summer wets these trap materials and makes them unattractive.

REMEDIAL MEASURES

DROWNING

Uninfested potted fairy primroses, cyclamen, and ferns (*Nephrolepis scottii*) were placed in a vat of water at depths just sufficient to cover the soil surface. Submersion for 24 hours caused no apparent injury, but with 48 hours' submersion the fine rootlets died, and the leaves yellowed on both cyclamens and primroses. The ferns yellowed after 72 hours' submersion.

To test the effect of submersion on the insects, potted plants with larvae of *B. sulcatus* in the third or fourth instar were submerged for varying periods up to 72 hours without apparent harm to any of the larvae. Thirty per cent of the larvae were dead after 96 hours of submersion, 72 per cent after 6 days, and 100 per cent after 8 days. As the plants are injured by a much shorter submersion than is required to kill the larvae, this method, which had been advocated by Kemner (*27*), can not be recommended for use in greenhouses.

Crowley (*7*) recommends winter flooding of cranberry bogs in Washington State for the control of the larvae; Feytaud (*15*) recommends similar treatment for vineyards. The dormant plants would be much more tolerant of flooding than would the tender, growing, greenhouse plants.

INSECTICIDES FOR CONTROL OF LARVAE

Since larvae destroy the subterranean parts of the host plants, whereas the adults attack the aerial portions, different control methods must be employed against the two stages of the insect.

Many authors have suggested methods of control, especially against the partly or nearly grown larvae. This is natural since the insect is usually not observed in the adult stage, and the larvae do not produce

conspicuous injury until the fourth or fifth instar. In the present studies nearly all of these suggested methods have been tested, and the results, though usually negative, have been briefly summarized.

The following materials were made up in varying concentrations, and sufficient quantities to just saturate the soil in the pot were added to each plant: Nicotine sulphate, free nicotine solution (soap and tobacco (*12*)), kerosene emulsion (*48*), kerosene-nicotine oleate, nicotine oleate, liquid extract of derris, pyridine, beech-wood creosote, coal-tar creosote (*12*), potassium thiocarbonate (*35*), sodium cyanide solution (*7*), carbolic acid emulsion (*48*, *49*), and calcium cyanide mixed with the topsoil (*41*). All these killed primroses and cyclamens without harming the third and fourth instar larvae.

Tobacco stem mulch (*54*) was found ineffective against larvae or eggs and was considered impractical of application in the greenhouse. Flake naphthalene (*21*, *34*) mixed with potting soil in varying quantities up to 8 ounces per bushel of soil was found ineffective against newly hatched larvae introduced 30 days after the plants had been potted in the treated soil. The naphthalene had very likely vaporized before the introduction of the larvae; therefore this material would not be effective against larvae over the usual 2½ month oviposition period of the adults during the summer. Naphthalene, introduced into holes made about the crowns of infested plants, was also ineffective against larvae in the third instar. Finely pulverized paradichlorobenzene applied about the crowns of plants and covered with soil, killed all larvae in 4-inch pots when applied at the rate of one-fourth gram per pot. No injury to cyclamens was observed when it was applied at rates up to a three-fourths of a gram per pot. This method of application, although encouraging in results, probably would not be practicable commercially because of the care and time required. This material dissolved in 70 per cent ethyl alcohol or in gasoline was very toxic when applied in smaller dosages. The application of carbon disulphide, with a pipette, into holes about the crowns of plants was found to be unsuccessful, as Swaine (*48*) and Gibson and Ross (*20*) had also found it. Carbon disulphide emulsion, even when applied at much greater concentrations than were recommended for the Japanese beetle (*29*), gave inconsistent results and no control at concentrations tolerated by the host plants. In the nursery, one series of tests on level, fairly dry soil at a temperature of 52° F. was made with carbon-disulphide emulsion, as suggested by Britton and Zappe (*6*, *p. 163*), but the result was only 40.9 per cent control of third-instar larvae.

Lead Arsenate Treated Soil

The results of the use of lead arsenate against Japanese beetle larvae (*Popillia japonica* Newm.) in the soil, as recommended by Leach and Lipp (*30*) suggested tests which were made with a view to controlling the larvae of *Brachyrhinus sulcatus* in the greenhouse and nursery and noting the effect on the host plants.

FOR POTTING GREENHOUSE PLANTS

The study of the life habits of *B. sulcatus* under greenhouse conditions showed that infestation normally takes place during the oviposition period, between early in July and early in September. The florist usually repots his cyclamen plants in May or June, and again

for the last time in August, when he is preparing his crop for sale the following Christmas. Since for this purpose the florist mixes together definite quantities of composted soil, leaf mold, sand, or sifted ashes it was considered that powdered lead arsenate, in determined proportions could be added to these ingredients at the time of mixing.

In the laboratory tests, lots of uninfested host plants were grown in soil containing known quantities of lead arsenate. As soon as rootlets appeared on the outside of the ball of soil, as observed when the plant is knocked out of the pot, newly hatched larvae were placed between the soil particles among these rootlets with a camel's-hair brush. The plant was then carefully replaced in the pot and labelled. At the end of two or three months, if the larvae survived they were nearly grown and could be easily found, and the results of the tests recorded. (Table 14.)

TABLE 14.—*Data of tests with powdered lead arsenate as a soil insecticide for greenhouse use against the larvae of Brachyrhinus sulcatus at Willow Grove, Pa., 1926–1928*

Treatment (ounces of lead arsenate per bushel of soil)	Larvae introduced	Pots in test	Results					
			Pots uninfested	Pots infested	Larvae recovered		Plants destroyed	
	Number	*Number*	*Number*	*Number*	*Number*	*Per cent*	*Number*	*Per cent*
Check, no lead arsenate	2,584	258	15	243	1,318	51.0	227	87.98
⅛	101	9	0	9	26	25.74	9	100.0
¼	269	21	7	14	48	17.84	14	66.7
½	1,735	111	95	36	95	5.47	27	24.32
1	3,566	269	265	4	4	.11	0	0
2	3,645	273	273	0	0	0	0	0
4	1,137	112	112	0	0	0	0	0
8	420	40	40	0	0	0	0	0

The primroses (*Primula malacoides* and *P. obconica*), ferns (*Nephrolepis* var. *scottii* and *N.* var. *verona*), and cyclamen, transplanted to the treated soil grew as vigorously as similar lots growing in untreated soil. The cyclamen plants were tested in soil containing various proportions of lead arsenate, with a maximum of 8 ounces per bushel, and exhibited no apparent difference from the checks. Fairy primroses tested in soil containing 16 ounces of lead arsenate per bushel of soil had a slightly more glistening foliage than the checks, but this did not detract from the appearance of the plants. The most striking difference between the plants was the blooming of the treated ones three weeks before the check plants. The roots of *Cuphea ignea* and of geraniums, however, were killed by this treatment.

In June, 1927, a florist potted two lots of 100 cyclamens each with his regular potting soil in which the writer had also mixed powdered lead arsenate in the proportion of 2 and 4 ounces, respectively, per bushel. Both lots of plants developed through the summer with the checks—the remainder of the crop—and were among the first to bloom in early November. Upon visiting the greenhouse on November 25, the author found that the florist had met the demand of his trade by picking out the plants in full bloom. The writer found that only 3 of the 200 plants with the treated soil remained, but that fully three-fourths of the checks remained unsold.

This florist grew his entire 1928 crop of 2,000 plants successfully in soil containing 2 ounces of lead arsenate per bushel. Only 2 plants were lost through larval injury by *Brachyrhinus sulcatus* whereas theretofore the losses had averaged 150 to 300 plants annually.

The above tests show that the use of soil containing lead arsenate appears to be safe for repotting cyclamens and primroses which are being transferred from 2-inch or 3-inch pots to larger ones. In repotting, the practice of removing the surface layer of the soil about the crown of the plant, before placing it in the larger pot, should be followed. This is a usual procedure with many florists, as the hardened surface layer, often incrusted with algae, can then be replaced with fresh soil. When treated soil is used for control of larvae of *B. sulcatus*, according to the potting methods just described, a layer of poisoned soil is presented to the young larvae as it attempts to penetrate to the roots.

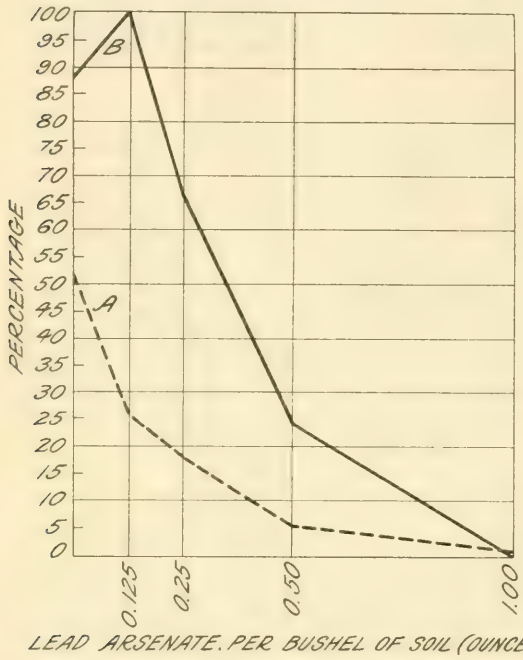

FIGURE 16.—The effect of varying quantities of lead arsenate in the potting soil upon the larvae of *Brachyrhinus sulcatus* and the percentage of plants destroyed by the insects, Willow Grove, Pa., 1926–1928: A, Percentage of larvae surviving; B, percentage of plants destroyed

From the detailed laboratory tests conducted over a period of three years and summarized in Table 14 and Figure 16 the conclusion may be drawn that effective control of the larvae of the black vine weevil is not obtained by using the proportion of one-half ounce or less of lead arsenate per bushel. The proportion of 1 or 2 ounces per bushel will insure practically complete protection from the larvae if the poison and soil have been thoroughly mixed. This latter precaution can not be overemphasized since the larvae, to be poisoned, must ingest some of the lead arsenate.

FOR OUTDOOR INFESTATIONS

To determine the quantity of lead arsenate necessary to control *B. sulcatus* larvae in the field, duplicate plots were treated with lead arsenate in proportions of 500, 1,000, and 1,500 pounds, respectively, per acre. The first 4 inches of surface soil was thoroughly mixed with the lead arsenate. All plots were planted with fairy primroses and sheep sorrel. Newly hatched larvae of *B. sulcatus* were placed at the base of each plant between August 1 and 20, 1927, at the rate of 180 per square yard. Examination of the plots on April 3, 1928, revealed the results shown in Table 15.

TABLE 15.—*Results of tests with lead-arsenate-treated soil in the field against larvae of Brachyrhinus sulcatus at Willow Grove, Pa., 1927–28*

Plot No.	Lead arsenate per acre	Larvae introduced per 2 square yards Aug. 1–20, 1927	Larvae found Apr. 3, 1928	Plot No.	Lead arsenate per acre	Larvae introduced per 2 square yards Aug. 1–20, 1927	Larvae found Apr. 3, 1928
	Pounds	*Number*	*Number*		*Pounds*	*Number*	*Number*
1	(1)	360	56	5	(1)	360	73
2	500	360	6	6	1,500	360	0
3	1,000	360	0	7	1,000	360	0
4	1,500	360	0	8	500	360	4

[1] Check, no poison.

CONTROL EXPERIMENTS WITH ADULTS

Feytaud (*16*) and Miles (*34*) reported on the use of lead arsenate sprays for control of adults of *Brachyrhinus sulcatus*. In the United States the first satisfactory control of the adults of the strawberry root weevil (*B. ovatus*) was obtained by applying a bait (*33*) consisting of 95 pounds of apple pomace dried to about 20 per cent moisture content and coated with 5 pounds of magnesium arsenate, zinc arsenite, or calcium arsenate. Mote and Wilcox (*36*) stated that a poisoned bran bait was as efficient as the dried-apple bait in the control of *B. ovatus* and *B. rugosostriatus*.[6] Their experiments showed that the attractive quality was sweetness, which led to the development of the following formula:

Bran	5 pounds
Molasses	1 pint
Calcium arsenate	4 ounces
Water	2 quarts

They reported that 93.93 per cent of the weevils were killed with this material as compared with 85.33 per cent with the apple bait.

The writer made several tests early in July before oviposition began with both baits in cages and on a screened bench in a greenhouse against known numbers of *B. sulcatus*. The mortality averaged 96.3 per cent of 314 adults with the apple bait, and 97.1 per cent of 340 adults with the poisoned bran bait in parallel tests. It was evident that the bran bait, especially, was attractive only while moist. Therefore baits applied in the evening gave better results than those applied in the morning and allowed to dry during the day. Watering of the plants after application or before the adults had been exposed overnight to the material reduced the percentage of kill.

Two dusts, one a mixture of equal parts of calcium arsenate and hydrated lime, and the other pure sodium fluosilicate; and a lead arsenate spray, as used by Mote and Wilcox (*36*), also gave encouraging results in cage tests against *B. sulcatus* when used by the writer.

No greenhouse was found in which adults were numerous enough to enable a test to be made on a commercial scale, but a moderately heavy infestation of the yew (*T. cuspidata*) offered an opportunity to test the materials (baits, dusts, and sprays) under nursery conditions. About one-third of the yew block was used in making the first test (Table 16, series A), and the remainder was used for the second series

[6] Mote and Wilcox used the name *rugifrons* under the supposition that this and the European species were the same.

of tests (B of the same table). The spray was applied to these plants in the afternoon, and the dusts and baits were applied at dusk during fair weather. The nurseryman objected to the foliage stain caused by the lead arsenate spray and to the burning caused by the sodium fluosilicate, so these two materials were not applied in the second tests.

TABLE 16.—*Summary of tests to control Brachyrhinus sulcatus on Taxus, Chestnut Hill, Pa., 1928*

Series	Material	Date of application	Date examined	Adults dead	Adults living	Adults killed
				Number	*Number*	*Per cent*
A	Bran bait	July 18	July 24	53	9	85.48
	Apple bait	do	do	68	45	60.18
	Calcium arsenate–hydrated lime dust	do	do	288	54	84.21
	Lead arsenate spray, 3 pounds to 50 gallons	do	do	87	68	56.13
	Sodium-fluosilicate dust	do	do	87	21	80.56
	Check	do	do	2	191	1.04
B	Bran bait	July 26	Aug. 4	148	34	81.32
	Apple bait	do	do	64	53	54.70
	Calcium arsenate–hydrated lime dust	do	do	157	10	94.01
	Check	do	do	2	153	1.29

These tests, made on yew plants from 3 to 4 feet in height with their very fine needles, presented conditions less favorable for good results than did the strawberry plants used by Mote and Wilcox in tests against other species of Brachyrhinus. The results were very encouraging, however, and indicated that the calcium arsenate-hydrated lime dust or the poisoned bran bait decidedly reduced the numbers of adult *B. sulcatus* in the nursery. The greater efficiency of the bran than of the apple bait was doubtless due to the former adhering to the foliage and lodging among the branches in much greater quantities than did the latter. Those weevils hiding in the trash among the branches or under loose bark did not come in contact with the apple bait which dropped to the ground; hence smaller numbers were poisoned. The bran bait may also be used inside and outside the greenhouse during the early part of July to kill the adults just before oviposition begins. If the material is applied only inside, adults from outside will later enter the greenhouse and oviposit. Because of the possible injury arising from the use of dusts or sprays, florists and nurserymen will doubtless prefer the bran bait for the control of adults of *B. sulcatus*.

SUMMARY

The black vine weevil, *Brachyrhinus sulcatus*, has been found frequently in greenhouses and nurseries in southeastern Pennsylvania and has often been recorded as doing damage to crops in North America, Europe, and Australia. A review of the literature of this pest shows 52 recorded host plants, and to this number 25 new ones have been added as a result of the present studies.

The adults devour foliage or flowers by eating from the margins. They also notch petioles and girdle shoots, which die beyond the point of girdling, the new growth producing a witchs'-broom effect. The young larvae feed on the rootlets. The more mature ones cut off the larger roots and gouge out the crowns of herbaceous plants, or

girdle the roots of woody plants. Injury caused by larvae, although often less conspicuous, is more severe than that caused by the adults.

The eggs are usually dropped by the adult wherever she may be, but sometimes they are apparently placed in the soil or plant crevices. The incubation period averages 15 days, with extremes of 11 and 22 days.

The larva molts five or six times during its development in the soil, and the normal period of development ranges from 72 to 113 days, though cold weather may interrupt development during the winter. The mature larva forms a cell in the soil and enters the prepupal stage which lasts from three weeks to eight and one-half months, depending upon the temperature.

The pupal stage ranges from 15 to 22 days with an average of 18 days.

The adult spends an average of 8 days, with extremes of 4 and 17 days, in the cell before emerging. During this time the body fully hardens and darkens in color. Adults feed at night on foliage or flowers and hide during the day. The preoviposition period ranges from 4 to 10 weeks.

In the greenhouse isolated adults laid an average of 661.4 eggs the first season and 374.8 eggs the second. The maximum number of eggs laid by one adult for two seasons was 1,681. The adult life of one weevil was 671 days; its age from egg to death of adult, 816 days. In the greenhouse weevils oviposit during July and August, and the larvae mature from October to December. These develop into adults from January to March and oviposit during the succeeding summer on the next crop of plants.

Out of doors, *B. sulcatus* passes the winter in the nearly full-grown larval, prepupal, or, less frequently, adult stage. In some years the larvae complete development before fall, but in most years a greater part of the larvae hibernate before completing growth. These immature larvae complete feeding early in the spring and pupate with overwintering prepupae in May or June. Adults emerge in June or July, oviposit during July and August, and go into hibernation in September, most of them dying, however, before spring. The few adults hibernating successfully emerge in May and oviposit through the second summer. The eggs laid early hatch to larvae which mature in the fall and spend the winter as prepupae. Out of doors adults laid up to 488 eggs during the first season with an average of 216.1. One adult deposited 863 eggs in two seasons. The number of eggs laid varied with the species of host plant fed upon.

There is, then, one annual generation, but there is also a partial overlapping of adults of the main generation with the few hibernating adults from the preceding one.

Reproduction in six generations was entirely by parthenogenesis; no males were found during the course of these studies.

No true parasites were found in these studies, but larvae were killed by the larvae of a carabid beetle, by an ant, *Formica* sp., and by two fungi, *Isaria* sp. and *Fusarium* sp. Skunks, mice, and toads were found to eat the adults.

As a result of life-history studies and control experiments, the following recommendations for control are given:

(1) Preventive measures. Remove all infested plants from the greenhouse before the emergence of the adults. Dispose of the soil

from all greenhouse plants which have been destroyed by the weevil larvae in such a way that the latter can not mature to adults and reinfest the succeeding crops. Sterilization by steam or prolonged submersion in water should be resorted to if the soil is to be used again. Otherwise the soil should be dumped at some distance from the greenhouse. Eliminate, as far as practicable, all outdoor hosts about the greenhouse. Erect barriers or screen the plants during July and August to prevent the entrance of adults.

(2) Remedial measures. To control the larvae thoroughly mix lead arsenate in the potting soil at the rate of 1 or 2 ounces per bushel. The larvae are then poisoned as they burrow into the soil in search of roots. To control the adults, apply calcium arsenate-hydrated lime dust, poisoned bran bait, or poisoned apple bait to the host plants early in July before egg laying begins. If staining of foliage is objectionable the poisoned baits are to be preferred.

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TECHNICAL BULLETIN NO. 324 SEPTEMBER, 1932

AN ECONOMIC STUDY OF THE PECAN INDUSTRY

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CONTENTS

	Page
Introduction	1
Production	2
Geographic distribution of pecan trees	2
Location of pecan-producing districts	2
Production of pecans	4
Number of pecan trees	8
Ages of improved pecan trees	9
Trend of future production	10
Principal varieties of pecans	10
Size of pecan holdings	11
Trend in pecan plantings as indicated by census figures	12
Pecan condition reports and forecasts	12
Cost of production	14
Explanation of items	15
Farms studied	16
Planting distances of pecan trees	19
Control measures for pecan scab infestation	20
Cost of production—Continued.	
Control measures for pecan insects	22
Yield of pecans	23
Cost of developing pecan orchards and cost of operating bearing orchards, by districts	26
Marketing	62
Shipping-point practices	63
Shipping-point prices	65
Distribution of the 1928 improved crop	67
City market survey	69
Chain-store and consumer survey by mailed questionnaires	78
The shelling industry	85
Competition of pecans with other nuts	85
Summary	87

INTRODUCTION

Pecans are an important source of farm income in many districts in the Southern States. During the five years ending with 1930 the farm value of pecans averaged about $9,600,000 per year. Pecan trees have been planted in large numbers in the last decade and increasing market supplies are indicated. In this period of expansion it is important that facts relating to the trend in production and costs of production and information on the long-time outlook for marketing be available for the guidance of those interested in the production or marketing of pecans.

This bulletin presents the results of an economic study of the pecan industry, conducted by the Bureau of Agricultural Economics, United States Department of Agriculture, in cooperation with various State agencies. The study was made during the period 1928–1930. Its purpose is to supply basic economic information which will assist in the sound development of the pecan industry.

There are three phases of the study: (1) Production, which includes estimates of the size of the pecan crop, the survey of the num-

ber of pecan trees by age groups and geographic distribution, varieties grown, and related topics; (2) cost of production, which deals with practices and costs in the development of pecan orchards of improved varieties and in the operation of bearing orchards; and (3) marketing, which includes a description of marketing practices in producing areas and in the markets, and a presentation of price and distribution data. The survey also includes information on pecan-marketing conditions from the view point of the retailer and consumer and a discussion of the competition of pecans with other nuts.

PRODUCTION

GEOGRAPHIC DISTRIBUTION OF PECAN TREES

The native range of the pecan covers a large area, extending from the valleys of the lower Ohio and Missouri Rivers and their tributaries, such as the Wabash, Illinois, and Osage, through the broad alluvial flood plains and delta lands of the Mississippi and its tributaries southward to the Gulf, and thence westward to the borders of the highlands of western Oklahoma and Texas. To the southwest the native trees are abundant in the valleys of all of the west Gulf rivers, such as the Trinity, Colorado, and Brazos down to the Rio Grande. Native seedling trees are occasionally seen as far east as western Alabama. Throughout this area, roughly 2,000 miles in length and from 200 to 600 miles in breadth, these trees, often of impressive size, have for ages shed their crops—food for man and beast.

Supplementing this area of natural pecan growth there has been a phenomenal expansion of the range of this valuable tree, especially during the last 50 years, through plantings of improved varieties on a large scale, in orchards for commercial production as well as around homes, throughout the entire east Gulf and South Atlantic coastal plains and the lower piedmont areas, from Mississippi to southern Virginia. Plantings have long been made in limited sections of California, but commercial production in that State has not thus far been significant. In restricted sections in Arizona recent plantings are thriving. West of the Mississippi, in the areas to which the pecan is native, progress in the planting of improved varieties, and especially in the top working of trees in native groves to improved varieties, has been rapid.

LOCATION OF PECAN-PRODUCING DISTRICTS

The location of pecan-producing districts shown in Figure 1 is approximate, based upon the evidence of the special 1929 pecan survey supplemented by census figures. In Texas the distribution shown is based largely upon the record of car-lot shipments out of the different counties and probably gives undue prominence to counties with important shipping points as contrasted with those lacking such shipping points. The improved pecans—that is, those from grafted, budded, and top-worked trees—come mostly from the States east of the Mississippi River and the seedling or wild nuts from the native pecan belt lying along the Mississippi River and the alluvial bottoms of the streams west of the Mississippi. The lower Ohio and Illinois bottoms and those of the streams of western Kentucky and Tennessee

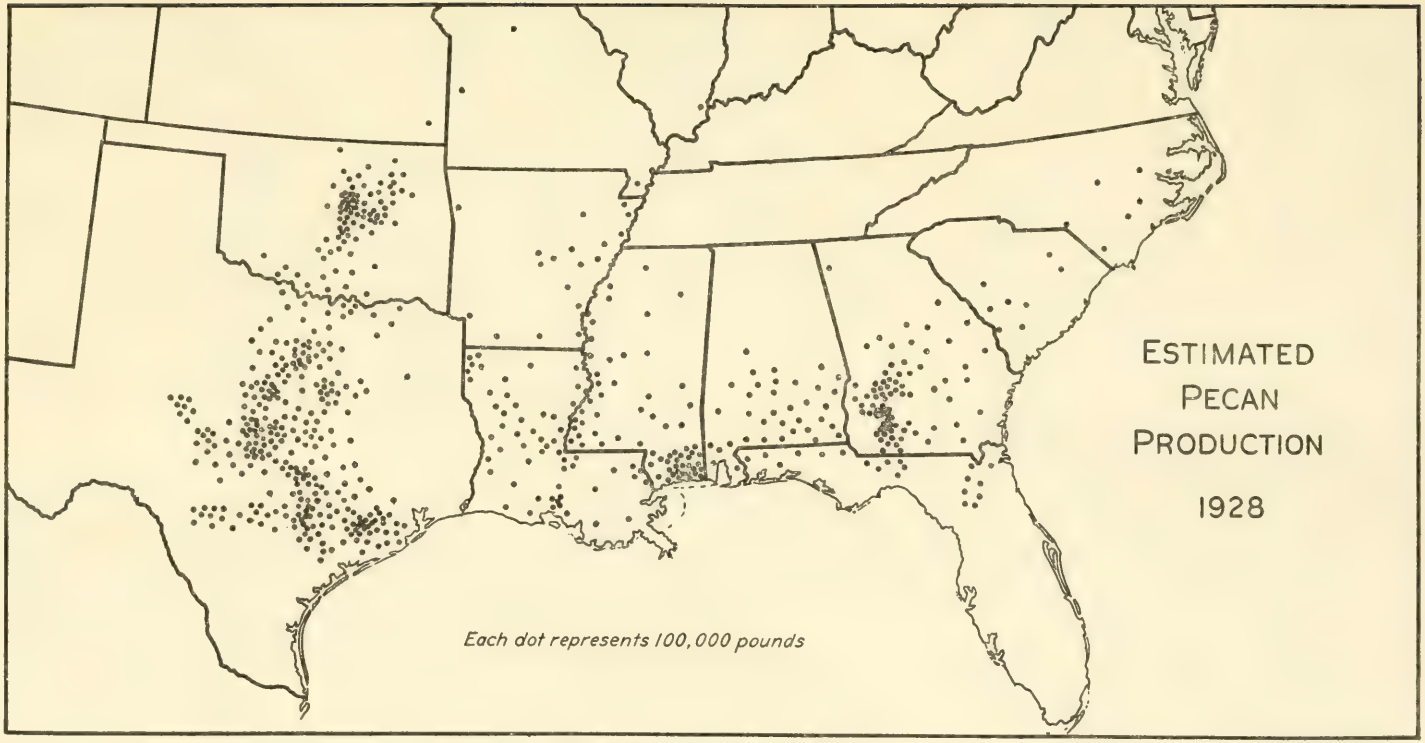

FIGURE 1.—The improved varieties of pecans are grown mostly in the States east of the Mississippi River, whereas the seedling or wild nuts are produced in the native pecan belt along the Mississippi River and farther west. The production of improved varieties in the native pecan belt is increasing

supply a relatively small production of wild pecans, and there is a considerable production in the Yazoo bottoms of Mississippi and in the lowlands of the southwestern corner of that State. On the other hand, a considerable production of improved pecans is found in southern Louisiana and considerable plantings of improved nuts are beginning to come into bearing in Louisiana, Texas, and Arkansas, although the production of these is as yet relatively insignificant there compared with production of the native seedling trees.

In the areas of native growth from Mississippi and Louisiana westward the pecan is found mainly in the river valleys and flood plains rather than upon the higher lands. Figure 1 does not always clearly indicate this fact, production being shown rather on the county basis and without strict localization. In the Southeastern States, where plantings have been by human design rather than by the operation of natural laws, this limitation to lowlands does not apply, although the pecan appears to do best in valley types of soils and in locations in which it has access to supplies of subsoil moisture.

PRODUCTION OF PECANS

The 1929 survey showed that the previous estimates of the United States Department of Agriculture on production of pecans, which had been based largely on the census of 1920 with allowance for subsequent increase, were much too low. The production of 1919 in the 12 States was (according to the census) 31,443,800 pounds on more than 100,000 holdings. The 11,000 groves and holdings included in the 1929 survey produced approximately 14,000,000 pounds of pecans. As judged from the survey and from the study of rail movement and other means of disposal, the total production of these 12 States in 1928, originally estimated at 42,000,000 pounds, was actually about 67,000,000 pounds. The original census deficiency was no doubt considerably greater in the native pecan belt, where a large proportion of the production is from wild trees not closely observed by the owners and often harvested by others, than in the East, where most of the trees are in orchards or around homesteads. Of the total census production of pecans in 1919, about 19 per cent was credited to the Eastern States, where a large proportion of the nuts are of improved varieties; whereas the survey and other checks show over 32 per cent of the pecan crop of 1928 to have been produced in that area. Of the total production in 1928, it is estimated that approximately 17,680,000 pounds were of improved varieties and about 49,620,000 pounds were of seedling and wild varieties.

Table 1 shows the census figures on production in 1919 and the estimates for 1928 based upon the survey in the spring of 1929 and subsequent checks of rail shipments and other information.

The revised estimates of total production of pecans for the years 1919–1931 appear in Table 2.

TABLE 1.—*Production of pecans by States and sections, census, 1919, and estimate by type, 1928*

State and section	Production, 1919 (census)	Estimated production, 1928		
		Improved varieties	Seedlings and wild	Total
	Pounds	*Pounds*	*Pounds*	*Pounds*
North Carolina	145,753	440,000	250,000	690,000
South Carolina	525,783	550,000	180,000	730,000
Georgia	2,545,000	7,400,000	1,000,000	8,400,000
Florida	1,025,673	1,500,000	500,000	2,000,000
Alabama	1,180,000	2,780,000	720,000	3,500,000
Mississippi	1,592,177	3,250,000	3,250,000	6,500,000
Eastern	7,014,386	15,920,000	5,900,000	21,820,000
Illinois	182,347		30,000	30,000
Missouri	555,184	5,000	295,000	300,000
Arkansas	348,382	95,000	1,655,000	1,750,000
Louisiana	2,242,859	820,000	4,680,000	5,500,000
Oklahoma	4,296,642	40,000	8,360,000	8,400,000
Texas	16,804,000	800,000	28,700,000	29,500,000
Western	24,429,414	1,760,000	43,720,000	45,480,000
Total	31,443,800	17,680,000	49,620,000	67,300,000

TABLE 2.—*Production of pecans, by States and sections, 1919–1931*

[In thousands of pounds, i. e., 000 omitted]

State and section	1919	1920	1921	1922	1923	1924	1925
North Carolina	240	130	150	260	480	560	330
South Carolina	600	220	800	360	680	770	550
Georgia	3,200	1,550	4,500	1,500	6,600	3,600	6,400
Florida	1,200	440	1,200	880	1,600	1,300	1,916
Alabama	1,400	600	1,800	1,350	2,500	1,686	2,200
Mississippi	2,600	715	2,700	1,100	2,400	1,932	5,094
Eastern	9,240	3,655	11,150	5,450	14,260	9,848	16,490
Illinois	230	210	155	165	200	200	23
Missouri	1,000	250	350	750	350	500	600
Arkansas	2,000	280	1,500	180	1,500	1,000	1,570
Louisiana	5,000	700	5,600	600	4,250	1,750	5,530
Oklahoma	15,000	3,000	9,000	2,000	16,000	11,000	14,700
Texas	35,000	2,000	19,000	2,000	20,000	12,500	12,000
Western	58,230	6,440	35,605	5,695	42,300	26,950	34,423
Total	67,470	10,095	46,755	11,145	56,560	36,798	50,913

State and section	1926	1927	1928	1929	1930	1931
North Carolina	780	660	690	664	640	1,050
South Carolina	1,300	750	730	580	920	950
Georgia	9,400	5,000	8,400	4,000	4,700	8,500
Florida	1,516	1,144	2,600	1,000	1,150	2,350
Alabama	3,100	1,260	3,500	1,620	2,730	4,000
Mississippi	5,500	3,200	6,500	2,300	5,700	5,500
Eastern	21,596	12,014	21,820	10,164	15,840	22,350
Illinois	315	90	30	150	200	250
Missouri	1,500	400	300	900	600	1,800
Arkansas	3,000	1,500	1,750	1,000	1,500	2,800
Louisiana	6,000	2,250	5,500	2,500	8,000	6,000
Oklahoma	19,700	8,900	8,400	14,900	13,000	11,500
Texas	41,900	9,600	29,500	20,000	12,500	32,000
Western	72,415	22,740	45,480	39,450	35,800	54,350
Total	94,011	34,754	67,300	49,614	51,640	76,700

The production of pecans is difficult to estimate. There are little or no data in most States for measuring the degree of the incompleteness of the United States census of pecan trees and production. The estimates given herewith are based upon rail, water, and truck shipments, State records and surveys, for States for which these are available, with conservative allowances above the census figures in other States. They are subject to a considerable margin of error, especially for years prior to 1924. They do present a rough approximation of relative production as between States and for successive years.

The largest pecan crop of record was that of 1926, production being estimated at 94,011,000 pounds. This was a year of maximum production in all sections of the belt. The next greatest pecan year of the last 13 years for which definite estimates have been made was 1931, with an estimated production of about 76,700,000 pounds, and the estimates for 1919 and 1928 each exceed 67,000,000 pounds. The years of smallest production during the period were 1920 and 1922, with crops estimated at about 10,096,000 and 11,145,000 pounds, respectively. No other year of the period produced a crop estimated at less than about 35,000,000 pounds.

TABLE 3.—*Production of pecans, by type, and by States and sections, 1919–1931*

[In thousands of pounds, i. e., 000 omitted]

IMPROVED VARIETIES

State and section	1919	1920	1921	1922	1923	1924	1925
North Carolina	120	66	80	140	260	310	190
South Carolina	330	120	470	220	430	500	370
Georgia	2,100	1,050	3,100	1,070	5,000	2,900	5,200
Florida	600	230	650	490	930	780	1,200
Alabama	840	370	1,150	900	1,700	1,180	1,600
Mississippi	1,070	315	1,160	480	1,100	900	2,400
Eastern	5,060	2,151	6,610	3,300	9,420	6,570	10,960
Missouri	10	2	4	8	4	5	6
Arkansas	20	3	20	3	30	25	40
Louisiana	600	80	750	80	600	250	830
Oklahoma	40	10	30	10	70	50	75
Texas	250	20	120	20	200	125	130
Western	920	115	924	121	904	455	1,081
Total	5,980	2,266	7,534	3,421	10,324	7,025	12,041

SEEDLING AND WILD PECANS

North Carolina	120	64	70	120	220	250	140
South Carolina	270	100	330	140	250	270	180
Georgia	1,100	500	1,400	430	1,600	700	1,200
Florida	600	210	550	390	670	520	716
Alabama	560	230	650	450	800	506	600
Mississippi	1,530	400	1,540	620	1,300	1,032	2,694
Eastern	4,180	1,504	4,540	2,150	4,840	3,278	5,530
Illinois	230	210	155	165	200	200	23
Missouri	990	248	346	742	346	495	594
Arkansas	1,980	277	1,480	177	1,470	975	1,530
Louisiana	4,400	620	4,850	520	3,650	1,500	4,700
Oklahoma	14,960	2,990	8,970	1,990	15,930	10,950	14,625
Texas	34,750	1,980	18,880	1,980	19,800	12,375	11,870
Western	57,310	6,325	34,681	5,574	41,396	26,495	33,342
Total	61,490	7,829	39,221	7,724	46,236	29,773	38,872

TABLE 3.—*Production of pecans, by type, and by States and sections, 1919–1931*—Continued

[In thousands of pounds, i. e., 000 omitted]

IMPROVED VARIETIES

State and section	1926	1927	1928	1929	1930	1931
North Carolina	450	380	440	430	420	735
South Carolina	900	550	550	450	750	800
Georgia	7,900	4,400	7,400	3,600	4,300	7,820
Florida	1,030	800	1,500	750	900	1,880
Alabama	2,320	980	2,780	1,340	2,330	3,520
Mississippi	2,650	1,570	3,250	1,200	2,450	3,090
Eastern	15,250	8,680	15,920	7,770	11,150	17,755
Missouri	15	5	5	15	10	35
Arkansas	90	60	95	60	80	170
Louisiana	750	350	820	375	1,200	960
Oklahoma	100	40	40	70	70	115
Texas	840	190	800	550	300	960
Western	1,795	645	1,760	1,070	1,660	2,240
Total	17,045	9,325	17,680	8,840	12,810	19,995

SEEDLING AND WILD PECANS

North Carolina	330	280	250	234	220	315
South Carolina	400	200	180	130	170	150
Georgia	1,500	600	1,000	400	400	680
Florida	486	344	500	250	250	470
Alabama	780	280	720	280	400	480
Mississippi	2,850	1,630	3,250	1,100	3,250	2,500
Eastern	6,346	3,334	5,900	2,394	4,690	4,595
Illinois	315	90	30	150	200	250
Missouri	1,485	395	295	885	590	1,765
Arkansas	2,910	1,440	1,655	940	1,420	2,630
Louisiana	5,250	1,900	4,680	2,125	6,800	5,040
Oklahoma	19,600	8,860	8,360	14,830	12,930	11,385
Texas	41,060	9,410	28,700	19,450	12,200	31,040
Western	70,620	22,095	43,720	38,380	34,140	52,110
Total	76,966	25,429	49,620	40,774	38,830	56,705

Texas is the largest single producer of pecans, the crop usually amounting to from 30 to 50 per cent of the total production in the United States. Texas has occasional years of near failure, however, in which the State production has dropped to less than 20 per cent of the United States total. The next State in volume of total production is Oklahoma, producing ordinarily from 15 to 30 per cent of the crop. Of the States east of the Mississippi River, Georgia leads in production, with usually about 10 per cent of the total crop.

Table 3 shows the production of seedling and improved types of pecans separately for the years 1919 to 1931.

From 60 per cent to 80 per cent of the seedling nuts ordinarily come from Texas and Oklahoma and most of the remaining seedling nuts come from the States bordering the lower Mississippi. About one-tenth of the seedling nuts ordinarily come from the eastern group of

pecan States. On the other hand, the eastern group usually furnishes close to 80 per cent of the nuts from improved trees and the lower Mississippi Valley States furnish most of the remainder, Texas and Oklahoma producing only a small percentage of improved varieties. Georgia ordinarily supplies about 40 per cent of the nuts from improved trees, Mississippi and Alabama coming next, with from 10 to 20 per cent each of the improved varieties.

NUMBER OF PECAN TREES

The number of pecan trees both of the improved and seedling types is shown in Table 4.

TABLE 4.—*Number of pecan trees by type, and by States and sections, census, 1925, estimate, 1929*

State and section	Total		Improved [1]	Seedling or wild, 1929 [1]		
	1925 (census)*	1929 (estimate)	1929 (estimate)	Total	Bearing age	Nonbearing age
North Carolina	103,814	320,000	279,000	41,000	31,000	10,000
South Carolina	200,407	360,000	335,000	25,000	23,000	2,000
Georgia	2,367,960	3,505,000	3,415,000	90,000	70,000	20,000
Florida	524,096	690,000	625,000	65,000	50,000	15,000
Alabama	709,670	940,000	893,000	47,000	42,000	5,000
Mississippi	580,402	993,000	634,000	359,000	241,000	118,000
Eastern	4,486,349	6,808,000	6,181,000	627,000	457,000	170,000
Missouri	174,051	450,000	5,000	445,000	266,000	179,000
Arkansas	76,767	801,000	251,000	550,000	400,000	150,000
Louisiana	360,432	812,000	281,000	531,000	354,000	177,000
Oklahoma	1,038,918	2,900,000	500,000	2,400,000	1,800,000	600,000
Texas	2,418,543	6,660,000	660,000	6,000,000	4,460,000	1,540,000
Western	4,068,711	11,623,000	1,697,000	9,926,000	7,280,000	2,646,000
Total	8,555,060	18,431,000	7,878,000	10,553,000	7,737,000	2,816,000

[1] Improved trees are those that have been grafted, budded, or top-worked with scions or buds of improved varieties. Seedling trees are those grown from the seed, including native wild trees.

The number of native seedling trees can never be known accurately and it is difficult to make a satisfactory estimate of them. The Federal census enumerates only trees reported on farms. Great numbers in woods and on unoccupied lands not included in farms are not enumerated, and probably many trees which might properly be included in a farm enumeration are overlooked. The census of 1925 reported 4,069,000 pecan trees in Oklahoma, Texas, Arkansas, Louisiana, and Missouri. The greater number in these States are known to be seedlings, although in Arkansas and Louisiana a considerable number are reported in planted orchards. The 1929 survey, including over 11,000 holdings, indicated that the number of trees in this group of 5 States, including about 1,700,000 trees of improved varieties, was about 11,600,000 trees. The number of trees of improved varieties can be estimated more accurately. The 1925 census showed 4,486,000 trees in the 6 leading pecan States east of the Mississippi, most of which were improved varieties. Other evidence at that time supported larger figures, and the survey of 1929 indicated that numbers of trees in these 6 States had increased between 1925 and 1929 by almost 50 per cent. The total number of pecan trees in the entire country in 1929, judging by the survey, was

about 8,000,000 trees of improved types and more than 10,500,000 seedling and wild trees, or a total of more than 18,000,000 of all types. These figures do not take into account young trees in nurseries or the thickets of young saplings in the native pecan territory, and probably understate the number of wild pecan trees in the native pecan belt.

AGES OF IMPROVED PECAN TREES

The data in Table 5 refer to planted trees; the figures are significant as showing the rapid increase in plantings during recent years. Based upon study of ages for over 2,000,000 trees of improved varieties reported in the survey, about 5.4 per cent of the total were planted in 1929, and 36.8 per cent during the four years 1925–1928. Approximately 36 per cent of all were 10 years old and over and about 58 per cent were 5 years and over. Probably at least half of the total plantings of improved trees, therefor, were not yet of bearing age in 1929.

TABLE 5.—*Number of pecan trees of improved varieties, by age groups, and by States and sections, 1929* [1]

NUMBER OF TREES

State and section	Planted in 1929	1–4 years old	5–9 years old	10–14 years old	15–19 years old	20–24 years old	25–29 years old	30 years old and over	Total 10 years old and over	Total 5 years old and over
North Carolina	22,300	131,100	47,400	33,500	30,700	7,300	6,100	600	78,200	125,600
South Carolina	10,000	157,000	63,000	44,000	30,000	13,000	10,000	7,000	104,000	168,000
Georgia	109,000	1,014,000	919,000	697,000	482,000	130,000	51,000	13,000	1,373,000	2,292,000
Florida	12,000	156,000	175,000	119,000	60,000	75,000	25,000	3,000	282,000	457,000
Alabama	49,000	250,000	232,000	143,000	188,000	18,000	9,000	4,000	362,000	594,000
Mississippi	23,400	206,000	142,300	131,300	80,000	24,300	11,100	15,600	262,300	404,600
Eastern	225,700	1,914,100	1,579,700	1,167,800	870,700	267,600	112,200	43,200	2,461,500	4,041,200
Arkansas	30,400	143,800	31,700	20,800	14,500	3,500	3,400	2,900	45,100	76,800
Louisiana	9,280	87,350	46,307	33,743	56,518	32,899	8,717	6,186	138,063	184,370
Oklahoma	100,000	365,000	30,000	5,000					5,000	35,000
Texas	63,400	386,000	67,300	28,400	101,000	10,000	900	3,000	143,300	210,600
Western	203,080	982,150	175,307	87,943	172,018	46,399	13,017	12,086	331,463	506,770
Total	428,780	2,896,250	1,755,007	1,255,743	1,042,718	313,999	125,217	55,286	2,792,963	4,547,970

PERCENTAGE OF STATE TOTAL

North Carolina	8.0	47.0	17.0	12.0	11.0	2.6	2.2	0.2	28.0	45.0
South Carolina	3.0	46.9	19.1	13.1	8.9	3.9	3.0	2.1	31.0	50.1
Georgia	3.2	29.7	26.9	20.4	14.1	3.8	1.5	.4	40.2	67.1
Florida	2.0	25.0	28.0	19.0	9.6	12.0	4.0	.5	45.1	73.1
Alabama	5.5	28.0	26.0	16.0	21.0	2.0	1.0	.5	40.5	66.5
Mississippi	3.7	32.5	22.4	20.7	12.6	3.8	1.8	2.5	41.4	63.8
Eastern	3.7	30.9	25.6	18.9	14.1	4.3	1.8	.7	39.8	65.4
Arkansas	12.1	57.3	12.6	8.3	5.8	1.4	1.3	1.2	18.0	30.6
Louisiana	3.3	31.1	16.5	12.0	20.1	11.7	3.1	2.2	49.1	65.6
Oklahoma	20.0	73.0	6.0	1.0					1.0	7.0
Texas	9.6	58.5	10.2	4.3	15.3	1.4	.2	.5	21.7	31.9
Western	12.0	58.9	10.4	5.2	10.2	2.7	.8	.7	19.5	29.8
Total	5.4	36.8	22.3	16.0	13.2	4.0	1.6	.7	35.5	57.8

[1] Estimate based upon age distribution shown by 1929 survey supplemented by numbers of bearing age and nonbearing age reported by the census of 1925. Does not include estimates by age groups of the 5,000 improved trees estimated for Missouri in 1929.

TREND OF FUTURE PRODUCTION

It would seem that increase in production will be rather rapid during the next few years, but this will depend largely upon the attention received by the orchards and the extent to which insects and diseases are controlled. As with other crops, these difficulties tend to increase with concentration of production. There will probably be a considerable loss of trees planted during the five years ended in 1929, in accordance with usual mortality of young plantings, and some loss of older trees. Even assuming a mortality of 40 per cent in these young plantings and 15 to 20 per cent in older trees, the number of planted trees of bearing age would increase about 25 per cent by 1940, even if we include in those of bearing age in 1929 all trees 5 years of age or older. Although many trees reach bearing age later than 10 years, most of the improved trees 10 years and older in 1929 were then of bearing age. A large proportion of those in the group 5 to 9 years in 1929 had probably reached bearing age by 1932. In addition to this, in orchards in which the trees are properly spaced, the increasing bearing surface developed by the 16 per cent of trees from 10 to 14 years of age and the 13 per cent ranging from 15 to 19 years will by 1940 have contributed a further material increase to production.

The extent of increased production of improved varieties from these causes—that is, the increase in number of bearing trees and increase of bearing surface of trees now in production—might easily amount to 50 per cent or more within the decade. Increase from wild trees, if any, seems likely to be moderate. An increase even up to 100 per cent in production from improved trees would without allowing for any increase in seedling and wild nuts, increase the total production of pecans by only 25 to 30 per cent.

PRINCIPAL VARIETIES OF PECANS

Data on varieties are incomplete. Table 6 shows the varietal distribution so far as it could be estimated from the survey.

TABLE 6.—*Percentage of certain varieties of pecan trees grown in specified States and sections, 1929*

State and section	Stuart	Schley	Success	Money-maker	Van Deman	Miscellaneous improved [1]	Seedling or wild
North Carolina	40.0	18.8	3.6	1.8	.....	23.0	12.8
South Carolina	44.4	34.8	2.2	.....	2.8	8.9	6.9
Georgia	30.4	28.9	2.5	4.4	2.9	28.3	2.6
Florida	14.8	10.3	3.9	5.8	.....	55.8	9.4
Alabama	14.0	4.8	.....	.....	.....	76.2	5.0
Mississippi	33.1	4.5	15.6	.....	.....	10.7	36.1
Eastern	28.1	20.0	4.2	3.0	1.6	33.9	9.2
Missouri	.....	.....	.....	.....	.....	1.1	98.9
Arkansas	10.9	3.4	4.9	3.0	.....	9.2	68.6
Louisiana	19.4	2.5	3.0	1.0	.9	7.8	65.4
Oklahoma	3.0	.6	.7	.....	.....	12.9	82.8
Texas	1.6	1.2	1.2	.....	.....	5.9	90.1
Western	3.8	1.2	1.4	.3	.1	7.8	85.4
Total	12.8	8.2	2.4	1.3	.6	17.5	57.2

[1] Miscellaneous includes other named and unnamed varieties of improved trees and may include small percentages of the named varieties shown in the other columns; in Georgia, 2.5 per cent Pabst, 3.6 per cent Frotscher, 2.2 per cent Teche, 1.4 per cent Mobile, 4.9 per cent Alley, 2.9 per cent Delmas; 1.9 per cent Curtis; in Florida it includes 9.7 per cent Curtis, 9.6 per cent Moore, 1.9 per cent Frotscher, 7.3 per cent Teche, 0.9 per cent Pabst, and 0.8 per cent President; in Mississippi, 2.2 per cent Hale, 1.3 per cent Bass; in Oklahoma, 0.8 per cent Halbert and 0.5 per cent Burkett; in Texas, 1.8 per cent Burkett. Data for varieties are less complete than for other items of the survey.

SIZE OF PECAN HOLDINGS

The number of separate holdings of pecan trees in 11 producing States is placed in the United States census of 1925 at 215,185. This enumeration probably missed many trees on small holdings and is especially likely to have been deficient in sections in which there are many native trees in the fields or woods.

The number of holdings in these 11 States for 1929 is estimated at 266,727. (Table 7.) Most of the holdings are small, many consisting of only a few trees, but there is a considerable number of the larger holdings and these include by far the larger proportion of all pecan trees.

TABLE 7.—*Number of holdings of pecan trees, 1925 and 1929, and number of trees in holdings of stated sizes in 1929*

State and section	Total holdings		Number of trees in holdings of stated sizes, 1929 [1]					
	1925 (census)	1929 (estimate)	1–19 trees	20–49 trees	50–99 trees	100–499 trees	500–1,999 trees	2,000 trees and over
North Carolina	15,930	19,241	115,000	54,000	50,000	56,000	29,500	15,500
South Carolina	14,703	20,250	130,000	35,000	33,000	60,000	37,000	65,000
Georgia	40,849	51,200	472,000	170,000	208,000	965,000	650,000	1,040,000
Florida	12,947	16,000	84,000	70,000	75,000	210,000	113,000	138,000
Alabama	26,181	29,000	180,000	115,000	115,000	320,000	150,000	60,000
Mississippi	21,538	24,300	111,000	76,500	99,700	318,400	172,900	214,000
Eastern	132,148	159,991	1,092,000	520,500	580,700	1,929,400	1,152,400	1,532,500
Missouri	4,776	6,000	30,000	30,000	43,000	122,000	150,000	75,000
Arkansas	5,789	13,400	56,500	99,000	112,500	165,000	184,000	184,000
Louisiana	18,152	23,700	126,000	114,000	84,000	180,000	122,000	186,000
Oklahoma	18,362	26,300	146,000	166,000	159,000	717,000	845,000	867,000
Texas	35,958	37,336	160,000	230,000	280,000	1,180,000	1,850,000	2,960,000
Western	83,037	106,736	518,500	639,000	678,500	2,364,000	3,151,000	4,272,000
Total	215,185	266,727	1,610,500	1,159,500	1,259,200	4,293,400	4,303,400	5,804,500

[1] There are no positive data on number of holdings of different sizes, the census material not having been tabulated in form to show this information. These estimates are based upon a study of distribution by size for a number of representative counties in the important producing States.

Native groves in the western group of States, particularly in Texas and Oklahoma, commonly comprise the holdings of an individual along the course of a stream and sometimes in a broader forested area. The stand of timber is made up of varying proportions of pecans interspersed with trees of other species. Single holdings may extend for many miles along a stream and its branches. Along the larger streams where the lowlands spread widely from the watercourse the pecan trees may be scattered over a rather broad area, but in many cases they form only a narrow fringe along the bank of the stream. In the valleys of the Mississippi River and its tributaries the pecan is found scattered among the forest trees covering the broad areas of the alluvial flood plains. East of the Mississippi River lowlands the trees are mostly planted in orchards that often number many thousands of trees. Most of the extensive orchards are found on the lower coastal plains area, although smaller orchards are found scattered throughout the lower piedmont area.

It is estimated that in 1929 the holdings containing over 2,000 trees included a total of about 5,800,000 trees, or 32 per cent of the total; that holdings of 500 to 1,999 trees had a total of 4,300,000 trees,

or 23 per cent; holdings of 100 to 499 trees, a total of 4,300,000 trees, or 23 per cent; and holdings of less than 100 trees, a total of 4,000,000 trees, or 22 per cent.

Groves numbering over 2,000 trees in Texas contained 44 per cent of its huge total of 6,660,000 trees. Georgia and Oklahoma have about 30 per cent of their orchards or groves of this size, and Louisiana, Mississippi, and Florida 20 per cent or more.

The proportion of trees in holdings of different sizes has been estimated on the basis of rather scanty data, and the figures given in Table 7 should be considered as only rough approximations.

TREND IN PECAN PLANTINGS AS INDICATED BY CENSUS FIGURES

The center of pecan production has been definitely moving eastward, with an increasing proportion of the total crop made up of cultivated types. But the increase in the western part of the pecan section in the proportion of young trees as reported in the census of 1925, is significant of awakened interest and progress in that section. The trend in production is indicated by the following statement:

The census enumerations show the following numbers of pecan trees: In 1910, 3,203,000; in 1920, 4,806,000; in 1925, 8,555,000. Trees of bearing age were 48.3 per cent of the total number in 1910, 53.8 per cent in 1920, and 49.9 per cent in 1925.

Texas and Oklahoma had, in 1910, 77 per cent of the trees of bearing age; in 1920, 56 per cent; and in 1925, 48 per cent; whereas the States east of the Mississippi River had in these years, 17, 36, and 45 per cent of the bearing trees, respectively.

Of the trees not of bearing age, Texas and Oklahoma in 1910 had 41 per cent; in 1920, 25 per cent; and in 1925, 33 per cent. The States east of the Mississippi River had 51 per cent of the nonbearing trees in 1910, 68 per cent in 1920, and 60 per cent in 1925.

The increase in plantings in the eastern section since 1925 has continued at a rapid pace but in the western section, the native home of the pecan, increasing attention has been given to the planting of orchards of improved varieties of trees and to the top-working of native trees to improved varieties. Owners of western pecan lands are ceasing to cut large producing pecan trees for timber and are saving the native young growth by protecting the trees and thinning the stand of other timber. Under these conditions production of the ordinary native seedling nuts is likely to be maintained for a long time.

PECAN CONDITION REPORTS AND FORECASTS

Table 8 shows condition figures monthly from July 1 to October 1 by States and for the United States, from 1920 to 1930 as reported by producers to the Bureau of Agricultural Economics. Condition is in comparison with a normal or full-crop promise for the month stated. The November figures show reported production as a percentage of a full crop.

TABLE 8.—*Pecan condition stated as a percentage of a full-crop promise each month, July–October, and for November, the reported production as a percentage of a full crop, by States, 1919–1931*

State and month	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931
North Carolina:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
July		65	59	75	75	92	71	80	71	74	71	63	74
August					67	77	62	77	67	72	66	62	73
September	68	60	46	67	66	78	48	78	66	66	64	54	75
October					72	75	45	83	63	64	60	54	70
November		35	32	50	78	80	45	80	65	66	57	54	73
South Carolina:													
July		82	81	72	81	85	72	69	66	73	58	64	70
August					65	72	63	70	64	69	54	62	68
September	80	56	80	48	70	66	50	76	64	66	46	60	67
October					77	66	45	80	63	55	45	56	64
November		33	81	42	65	75	47	80	57	55	41	60	61
Georgia:													
July	79	34	79	45	89	76	77	78	55	76	52	53	71
August					83	65	67	73	54	73	44	46	70
September		34	80	36	78	52	62	75	52	70	38	46	75
October					78	50	59	77	50	62	36	44	70
November		31	70	22	77	42	61	79	46	68	33	39	64
Florida:													
July		39	62	77	86	76	87	76	53	74	54	55	72
August					83	65	80	70	49	75	42	46	75
September	70	40	70	55	83	60	80	72	52	70	48	48	72
October					80	59	80	61	52	68	44	52	77
November		32	68	50	75	60	80	60	41	68	40	44	76
Alabama:													
July		50	78	65	86	76	80	80	50	77	52	61	72
August					72	60	68	72	37	70	44	56	70
September	88	50	74	55	66	56	68	74	43	69	43	57	75
October					65	56	60	60	35	69	45	58	75
November		29		50	71	55	62	70	30	70	36	55	70
Mississippi:													
July	95	50	80	83	78	70	83	72	50	71	53	60	74
August					62	58	75	64	47	71	49	48	71
September		28	75	39	62	44	75	68	47	72	45	53	67
October					61	46	70	60	44	72	38	57	65
November		15	75	28	60	38	73	65	40	78	30	60	63
Arkansas:													
July				75	65		65	78	60	73	66	59	74
August					50	72	63	71	60	60	57	42	73
September	77	26	64	24	50	60	65	78	56	62	48	41	75
October					60		67	78	58	64	45	46	71
November	90	17	70	12	64	60	58	84	54	61	38	53	79
Louisiana:													
July		22	72	50	70	70	75	71	56	72	52	61	69
August					62	4	69	72	50	65	45	52	66
September	90	33	71	25	58	44	70	64	45	67	42	56	69
October					63	37	70	62	40	70	42	66	67
November		13	75	11	64	29	74	66	35	66	35	67	65
Oklahoma:													
July	97	55	50	76	77	82	65	69	64	48	61	50	61
August					63	68	59	67	58	40	52	43	53
September		20	46	36	57	60	58	68	54	44	48	41	48
October					67	59	58	70	51	34	50	44	47
November		15	47	9	68	46	56	68	40	33	51	48	46
Texas:													
July		30	51	34	66	66	44	64	43	50	60	46	65
August					53	52	25	63	35	50	53	35	60
September	85	30	44	9	51	40	20	60	35	52	40	33	58
October					50	35	25	65	32	56	40	32	56
November		8	45	6	49	30	29	72	23	39	42	27	58
United States:													
July	83.2	38.5	56.3	53.4	72.6	71.5	58.6	68.3	50.4	57.4	58.3	50.8	66.9
August					60.7	57.4	44.7	66.6	43.4	55.1	51.0	41.2	62.8
September		31.0	51.2	27.7	58.0	47.2	41.3	65.4	42.1	55.7	42.7	40.3	61.6
October					58.8	43.5	42.9	66.8	39.2	55.7	41.9	41.1	59.6
November		16.0	52.2	15.3	57.3	37.7	45.1	71.2	31.6	57.4	40.9	39.0	59.7

These figures have a relation to the final size of the crop, but it is not a close relationship in the early months. (Fig. 2.) The condition figure tends to approach closer each succeeding month to the November figure on percentage of full crop produced. The November figure itself usually fails to reflect the full extent of the variation from year to year in the actual production as finally estimated. Uncertainty lessens as the season develops. The condition figures tend to be too low in very good years and too high in bad years, but the tendency in most years is to be too high. Decreases are seen to be greater than increases. This is logical, as the crop has a limited possibility of improvement but might be almost totally lost under very adverse conditions.

Reports issued by the Department of Agriculture ordinarily show only condition on the first of the months of July to October, in per-

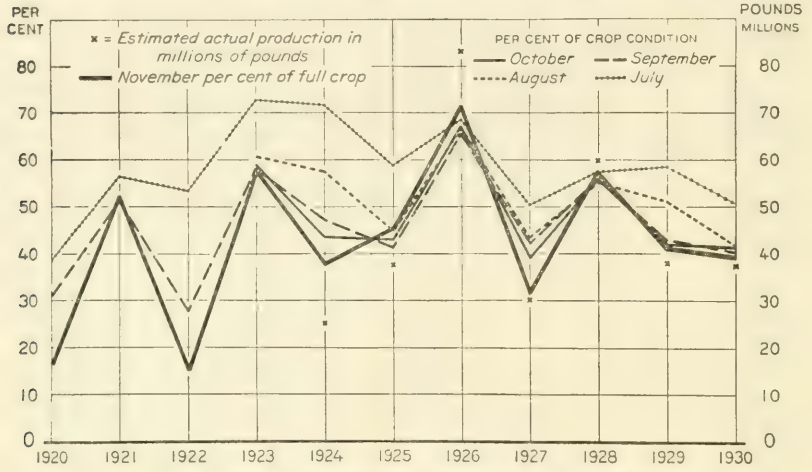

FIGURE 2.—Pecan reports for the United States, 1920–1930.

The relation between condition and production tends to become closer each month. The tendency in most years is for the early figures to be too high. Production was not estimated prior to 1924. (X represents preliminary estimates of absolute production. Revised estimates are shown in Table 2.)

centage of a full-crop promise, in comparison with previous months and years. Later in the season, forecasts and estimates may be made, based on study of the current reports of the crop condition in comparison with condition and final production in past years, on the reports of correspondents concerning production on their own farms, and on the personal investigations of agricultural statisticians of the United States Department of Agriculture in the different States. These are the principal available indications of production that can be used while the crop is still being marketed and until shipment records become available.

COST OF PRODUCTION

The cost-of-production data presented in this bulletin were obtained in the spring of 1929 by personal interviews with pecan growers in the leading pecan-producing districts of Georgia, Florida, Alabama, Mississippi and Louisiana. The data refer to improved varieties only.

The practices and expenditures in terms of physical quantities and money are based on the most common method of orchard development and management as now practiced by pecan growers. Methods and practices in the development of young pecan orchards and in the care of bearing orchards have undergone many changes during recent years, changes natural for an industry as young as the pecan industry. The old idea that it was necessary only to plant a pecan tree and let nature care for it until it came to bearing age has been proved a fallacy. Many growers now realize that pecan trees require as much care and attention as do other horticultural crops. Perhaps the greatest improvements have been in better cultural practices, better fertilization, including the use of cover crops, and more suitable planting distances for young orchards. Even though these improvements are rather widely known, many orchards at present receive such indifferent care that the owners do not realize a profit.

Cost estimates are shown for orchards that have received reasonably good care, but not necessarily the best care. Notwithstanding great variations in methods and practices, each district has a general predominating method of orchard management on which the cost estimates are based.

Where field crops were grown in the orchard for harvest, only a part of the cost of such items as preparation of the land and cultivation of the total orchard acreage and of the cost of taxes and of interest on the investment was charged to the pecan orchard. The basis for such charges was the extent of the land area used by the trees. This method assumes that the growing of interplanted cash and feed crops reduces the cost of certain items involved in developing the trees and in producing the nuts, in proportion to the land area used by crops grown in the orchard. This is an arbitrary and not altogether satisfactory basis for distributing these costs, but is the best that could be used under the existing circumstances. The costs as shown are based on prices paid for labor, materials, and other items, in 1928.

The cost of developing pecan orchards for the first 10 years was used to represent the cost of bringing an orchard into bearing age. No credit was given for the value of nuts produced during this period. In some districts some production before the eleventh year can be anticipated, especially from early-bearing varieties, but such production from most varieties is not of commercial importance.

The cost of operating bearing pecan orchards is shown for orchards of 15 to 19 years of age. The majority of the bearing orchards surveyed were of this age.

EXPLANATION OF ITEMS

Labor and power rates.—Charges for man labor are based on prevailing local rates for labor hired by the day in 1928. Rates for horse work are based on the estimated cost of keeping work stock. Charges for use of tractors are based on the estimated cost of operating tractors.

Supervision.—Supervision refers to the labor of a general supervisory nature performed by the owner or hired manager. This labor was charged at double the rate for ordinary labor.

Materials.—Such items as trees, commercial fertilizer, manure, cover-crop seed, and spray materials were charged at cost when purchased, and at farm value when produced on the farm.

Orchard sanitation.—Orchard sanitation includes such operations as knocking off scab-infested leaves and nut shucks in the winter, disposing of girdled twigs and limbs, destroying web worms, etc.

Rate of work per day.—The term "rate of work per day" refers to the amount of work done per day on the basis of the entire orchard acreage and accounts for the relatively large number of "orchard acres" covered a day for such operations as cultivating tree rows and applying fertilizer around trees, where only a portion of the actual orchard space is covered.

Reserve for orchard depletion.—A charge for depletion of the orchard based on its bearing life is usually included in a study of orchard costs. As the production of improved varieties of pecans has been under way for so short a time that no one knows the bearing life of an improved pecan orchard, no charge for orchard depletion is included in this study. There are records, however, of seedling pecan trees over 100 years of age which are still bearing. If improved varieties have as long a period of bearing life as seedlings, this charge would obviously be so small as to be almost negligible.

Overhead.—Overhead includes a charge for such items of general farm maintenance expenses as building and fence repairs, general farm insurance, and miscellaneous cash and labor items used in operating the farm. In this study overhead was estimated as amounting to 15 per cent of the cost of labor, power, and materials used in pecan production.

Interest.—During the development period, interest was figured for a specific year at prevailing rates on the previous year's development costs and on the original value of the land occupied by the trees and on the value of the machinery used in developing the orchard. The interest charge for bearing orchards was figured on the total computed cost of developing an orchard into bearing, plus interest on the value of the land occupied by the trees and on the value of machinery used in operating the bearing orchard. For orchards purchased, interest should be computed on the price paid. Orchards in some districts may sell for more than the cost per acre as computed in this study.

Use of machinery.—Machinery costs include depreciation and repairs for tillage implements and other machinery used in handling orchards, excluding tractors. The charge for tillage implements was estimated at 3.75 cents per horse hour used. Sprayer charges were estimated at 65 cents an hour of use.

Taxes.—The tax charge is a pro rata share of the 1928 land tax; the part charged to pecans is in proportion to the value of the land used by the pecan trees. In general, young pecan orchards are assessed at the same value as land of the same grade without trees.

FARMS STUDIED

Records were obtained on a total of 222 pecan farms located in nine important pecan-producing districts. (Fig. 3.) In all, 408 blocks of trees, each block representing a separate planting, were included in the study. In all these districts small orchards were found, but a number of the pecan farms studied had several hundred acres, which require the full-time services of the owner or manager and a corps of assistants. Some of the larger pecan farms are operated by companies or individual caretakers who care for the orchards of absentee owners. The holdings of these absentee owners are usually small, 5-acre tracts being

the most common size. In this study a group of these holdings under one management was considered as one farm. (Table 9.) Because of this fact these farms can not be said to be typical of individual holdings, so far as size of orchards is concerned. It should also be borne in mind that selection of these farms was necessary because of the desirability of interviewing men who had cared for their orchards for some time and because of the necessity of collecting facts on orchards that were in the developmental stage and on others that were of bearing age. The age of these orchards varied from less than 1 year to over 30 years, but in selecting a group on which to base an estimate of the cost of operating bearing orchards, those from 15 to 19 years of age were used. The majority of the bearing orchards surveyed were of this age.

Yield records obtained in the field were supplemented by information from a mailed questionnaire survey conducted by the Division of Crop and Livestock Estimates.

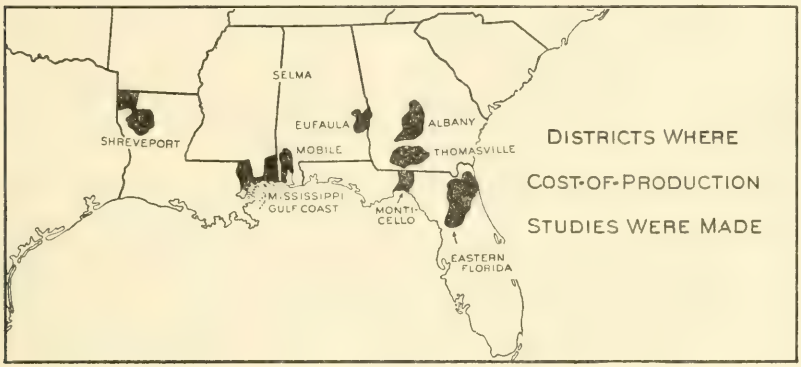

FIGURE 3.—Cost-of-production studies were made in nine of the principal districts producing improved varieties of pecans

TABLE 9.—*Number of farms studied, by States, and by acreage in pecans, 1928.*[1]

Acres in pecans	Georgia		Florida		Alabama			Mississippi—Gulf coast	Louisiana—Shreveport
	Albany	Thomasville	Monticello	Eastern	Mobile	Selma	Eufaula		
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
25 and under	3	0	18	23	5	3	3	22	1
26–50	4	2	6	7	3	3	4	4	2
51–75	1	1	1	5	1	1	1	6	3
76–100	3	2	0	4	1	3	1	2	2
101–125	1	1	3	2	0	1	0	0	1
126–150	1	1	0	1	1	1	1	0	1
151–175	4	2	0	0	0	0	0	3	0
176–200	4	0	1	1	0	0	0	1	2
Over 200	19	1	2	1	2	2	4	2	4
Total	40	10	31	41	13	14	14	40	16

[1] Many of the farms listed with large acreages are made up of small individual holdings (usually 5-acre tracts) under the same management.

Small individual holdings under one management are found most frequently in the Albany district of Georgia. This district represents one of the most extensive districts now producing improved varieties of pecans. Fifty-eight per cent of the farms studied had all of their

crop acreage in pecans; 42 per cent had only a part of their crop acreage in pecans, the remainder being planted to such crops as cotton, corn, peanuts, and hay. Usually cash and feed crops are produced among the trees of the young pecan acreage in this district. It is on the northern fringe of the Albany district that pecan orchards are operated in connection with the production of cotton and other field crops. In the central and southern part of the district pecan production is more specialized.

On the farms studied in the Thomasville district of Georgia the entire crop acreage was usually planted to pecans, although on a few farms the production of crops on land not in orchard was of some importance and consisted mainly of corn and hay, In the young orchards, the usual practice is to grow field crops for harvest.

In the two Florida districts crops are usually grown in the pecan orchard in the early stages of tree growth. On many of the pecan farms in these districts, such crops as corn, hay, cotton, peanuts, and melons are grown on land not in orchard. On other farms the entire crop acreage is planted to pecans. A large proportion of the pecan farms studied are relatively small.

On many of the pecan farms in the Mobile district of Alabama, Satsuma oranges are interplanted with the pecan trees and additional small acreages of cotton, corn, and hay are grown.

TABLE 10.—*Percentage distribution of blocks of pecan trees by age group, and by number of trees set per acre* [1]

Number of trees set per acre	Under 10 years of age	10 to 19 years of age	20 years of age and over	Number of trees set per acre	Under 10 years of age	10 to 19 years of age	20 years of age and over
	Per cent	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*
Under 9	9.2	3.2	3.8	21–23	3.5	6.9	6.4
9–11	4.2	3.7	2.6	24–26	2.1	.5	0
12–14	30.3	21.8	14.1	27–29	3.5	12.8	21.8
15–17	35.9	31.9	28.2	Over 29	.7	4.3	9.0
18–20	10.6	14.9	14.1				

[1] Based on 408 blocks of trees, each block representing a separate planting. (Table 11.)

In the Eufaula and Selma districts of Alabama and in the Shreveport district of Louisiana the majority of the pecan farms studied not only had crops in the young orchards, but they also contained a considerable additional acreage of cotton and corn, and in many instances, of oats, hay, and peanuts. In the Shreveport district crops are generally grown in the bearing orchards. Generally the acreage of field crops outside of the orchard exceeded the acreage devoted to pecans. It may be said that these districts represent the type of farming where pecans are produced in a more or less general farming system with cotton and corn the major farm enterprises.

Many of the pecan farms studied in the Mississippi Gulf coast district are relatively small. Although a few pecan growers plant truck crops and Satsuma oranges in the orchard, the general practice is not to intercrop the orchard. Many of the growers have additional small acreages for feed crops.

PLANTING DISTANCES OF PECAN TREES

In the early days of the pecan industry there was a tendency to set trees more closely together than has been the practice during recent years. Of 408 blocks of trees, more than 50 per cent of those that are 20 years of age and over were set at the rate of 18 or more trees to the acre; of those under 10 years of age only 20 per cent have as many as 18 trees to the acre and 44 per cent have 14 or fewer trees to the acre. (Table 10.) The square method of planting is the one most commonly used.

The variation in number of trees set per acre in the orchards studied is from 4 to 50. (Table 11.) However, 121 blocks of trees were set 50 by 50 feet, or 17 to the acre, and 82 were set 60 by 60 feet, or 12 to the acre. These are the two most common planting distances observed.

TABLE 11.—*Distribution of blocks of pecan trees by age group, and by number of trees set per acre* [1]

Number of trees set per acre	1 to 4 years	5 to 9 years	10 to 14 years	15 to 19 years	20 to 24 years	25 to 29 years	30 years and over
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
50				1			
48				2	2		
36				1	1	1	1
35		1	2		1		
32				1			
31			1				1
29					1		
27	2	3	10	14	12	2	2
24		3		1			
22			1	1			
21	3	2	5	6	4	1	
20	2	6	11	14	7		2
19	2	2	1		1		
18	2	1	1	1	1		
17	20	25	21	34	12	7	2
16	2	2	2				
15		2	1	2	1		
14	2	1	4	3		1	
13	1	1					
12	15	23	18	16	8	2	
11			2	3			
10	2	4	2		1	1	
8	1	3	1	1	1		
7	1	2					
6	1	2	1				1
5	2			1			
4		1	2		1		
Total	58	84	86	102	54	15	9

[1] A total of 408 blocks of trees, each block representing a separate planting.

The age at which pecan trees begin to crowd each other depends on the variety and to a large extent on the fertility of the soil. With reference to this point a published report [1] based on an orchard of the Frotscher variety at Thomasville, Ga., gives the information in the following paragraph.

Trees of the Frotscher variety in this section are vigorous growers and wide spreaders and crowd each other at an earlier age than do trees of some other varieties. At about 12 or 13 years of age trees of this variety set 50 by 50 feet, or about 17 to the acre, were very symmetrical and uniform in shape and had attained a growth which,

[1] PARKER, C. S. PROPER DISTANCE FOR TREES IN A PECAN GROVE. Natl. Pecan Growers Assoc. Proc. 1922: 48. 1922.

in many instances, allowed the limbs from adjacent trees to touch each other. During the next two years the lower limbs, with few exceptions, died, thereby greatly reducing the bearing surface of the trees. Later, the even numbers from the first row and the odd numbers from the second row (and so on) were removed, leaving the trees that remained at about 71 by 71 feet, or about 9 trees to the acre. Since the removal of the excess trees, the remaining trees have flourished and are again developing their rounded forms.

During the first few years of the bearing life of a pecan orchard, or up to the time the trees begin to crowd, a greater production per acre can be anticipated from trees set fairly close together. Notwithstanding the possibility of a greater yield for the first few years it is doubtful if this added production will more than offset the cost of carrying the excess trees through the development period and the cost of removing them when they begin to crowd. If the trees are set close together they should be so spaced that those remaining, after some have been removed, will be in a fairly symmetrical arrangement.

If the excess trees are not removed when they begin to crowd, nature will come to the aid of the trees in their search for sunlight and air and cause the lower limbs to die so that a large amount of valuable bearing surface will be lost. As there is always the danger that the removal of excess trees will be delayed too long, perhaps the safest course to pursue is to set the trees a greater distance apart. Table 11 shows that, as many of the recent plantings are set too close for the future well-being of the mature orchard, some of these trees should be removed after a few years of bearing life.

CONTROL MEASURES FOR PECAN SCAB INFESTATION

Some of the fungus diseases affecting the pecan are the brown leaf spot, blotch, downey-spot, and scab. Of all of these, pecan scab is of the most economic importance. This disease affects the leaves, twigs, and nuts of the pecan tree with by far the greatest injury to the nuts. It is most serious in districts of high humidity, high temperature, and frequent summer rains. Until recently pecan scab was not of great economic importance except in the southeastern United States within a distance of from 50 to 100 miles from the coast. Scab infestation has continued to spread, however, until it is fairly well distributed over the pecan belt except in the drier districts of the Southwest.

TOP-WORKING

Formerly many cultivated varieties of pecans were thought to be practically immune to scab infestation. The Teche, Curtis, Moneymaker, Russell, Stuart, and Frotscher were considered highly resistant. Of the cultivated varieties most susceptible to scab Delmas, Georgia, Alley, Van Deman, Schley, Pabst, Mobile, Success, and Moore may be classified in the order named.[2] Recent observations, however, indicate that the scab fungus is becoming of economic importance on the so-called highly resistant varieties.

As the effective control of this disease is a matter of great importance to the pecan industry the practice, widely followed, of top-working susceptible varieties to so-called nonsusceptible varieties may need

[2] DEMAREE, J. B. PECAN SCAB WITH SPECIAL REFERENCE TO SOURCES OF THE EARLY SPRING INFECTION. Jour. Agr. Research 28: 321–330, illus. 1924.

to be abandoned and other methods of control adopted. The cost of top-working to so-called nonsusceptible varieties and the time required for the top-worked tree to come into commercial bearing again are important items for consideration. So many factors enter that a reasonable estimation of this cost is difficult. Estimates indicate that the total cost of top-working including necessary care following will approximate $1 for each inch in diameter of the top-worked tree. The length of time before top-worked trees come into bearing again depends on a number of conditions, but it is safe to state that the new top will begin bearing in from 2 to 5 years and will yield a commercial crop in 6 to 8 years.[3]

COST OF SPRAYING AND DUSTING

In humid regions where scab is prevalent, spraying or dusting susceptible varieties may be essential to save the pecan crop. With indications of a heavy crop set in the spring, spraying or dusting these varieties may mean the difference between no crop and a full crop. The impression prevails in some sections that the cost of spraying and dusting is prohibitive. The estimates of the cost of these operations (shown in Table 12 for the year 1928) should serve to disprove this assumption.

TABLE 12.—*Comparative cost per acre per season of spraying, and dusting 16-year-old pecan trees set 12 to the acre according to a common method and at cost rates prevailing in 1928*

Item	Spraying		Dusting	
	Quantity	Cost	Quantity	Cost
Materials used, per acre:	*Gallons*	*Dollars*	*Pounds*	*Dollars*
Bordeaux mixture 3-4-50	900	4.86		
20–80 copper-lime dust			240	14.40
Applications	*Number* 3		*Number* 4	
Usual crew:				
Men	3		2	
Horses	2		2	
Cost per acre:	*Hours*		*Hours*	
Man labor	15.3	2.65	2	.38
Horse work	10.2	1.28	2	.25
Sprayer use	5.1	3.83	1	.75
Total		12.62		15.78

On the basis of 16-year-old trees set at 60 by 60 feet, or 12 to the acre, the cost per acre of three applications of a standard 3–4–50 Bordeaux mixture is about $12.60, while the cost per acre of four applications of a 20–80 copper-lime dust is about $15.80. Based on the recommended number of applications of wet spray and of dust (three and four, respectively) these figures show a somewhat higher cost per acre for dusting than for spraying. On a tree basis, the cost per season is $1.05 for spraying and $1.32 for dusting. With pecans selling at 30 cents a pound, about 3½ pounds of nuts per tree would pay for a season's spraying and 4½ pounds would pay for a season's dusting.

[3] BLACKMON, G. H. TOP-WORKING PECAN TREES. Fla. Agr. Expt. Sta. Bul. 170: 187. 1924.

On the farms visited in 1928 neither the practice of spraying nor that of dusting was commonly followed. Considering the increased yield that normally may be expected in humid districts, as a result of spraying or dusting varieties susceptible to scab, it appears that these control measures may be practiced to advantage.

A sprayer of sufficient power and capacity for effective work in old pecan orchards costs about $1,250, whereas a suitable duster costs about $500. To justify the purchase of a sprayer a grower should have not less than 25 acres of pecan orchard and for the purchase of a duster probably not less than 10 acres. Some pecan growers with small acreages may find it advantageous to own this equipment in partnership with neighbors.

CONTROL MEASURES FOR PECAN INSECTS [4]

Among the various insects which attack the pecan and cause damage, the pecan leaf case-bearer, the pecan nut case-bearer, the black pecan aphid, and the hickory shuckworm are of major economic importance; in limited localities the obscure scale and the pecan weevil are also of considerable importance.

The pecan leaf case-bearer occurs in very injurious numbers in orchards in the southern portion of the pecan-growing area, extending from Florida to Texas. This insect does not attack the nuts directly, but it destroys many blossom buds in the spring. As the initial activity of the larvæ of this insect in the spring is confined to the terminal and lateral buds after differentiation has taken place, the damage they do plays an important part in reducing the yields.

Pecan growers annually use considerable quantities of calcium arsenate in the control of this insect. This insecticide is used at the rate of 1 pound to 50 gallons of 3–4–50 Bordeaux mixture. Under no circumstances should calcium arsenate be used without Bordeaux mixture, as more or less serious injury to the foliage or nuts is likely to result if the mixture is not used. Only one thorough spraying is necessary to control this pest. This spraying should take place at the time of the last Bordeaux application for pecan scab, leaf blotch, or brown leaf spot—about July 15.

The pecan nut case-bearer has often been reported as destroying from one-third to three-fourths of the total crop of wild pecans in various localities in Texas. It is also present in Florida, Georgia, Alabama, Mississippi, and Louisiana, where it occasionally becomes a serious pest. Serious destruction in most of these localities occurs, on an average, in only one year out of five. Considerable study has been devoted to the problem of controlling the pecan nut case-bearer, but because of the peculiar habits of the pest no satisfactory practical control measure has yet been devised.

The black pecan aphid, like all other plant lice, feeds upon the sap which is sucked up through the beak thrust into the tissues of the leaf. The damage caused by this insect is difficult to estimate. In times of a severe infestation there is undoubtedly a drain which interferes with the proper functioning of the tree. Coupled with this, the premature defoliation resulting from the feeding of the aphids has a tendency to result in unfilled and undeveloped nuts. Owing to the fact that it takes considerable spray material properly to spray large

[4] For further information on pecan insects and their control see Farmers' Bulletin 1654, Insects of the Pecan and How to Control Them.

pecan trees, growers are rather reluctant to use nicotine sulphate 40 per cent, which is at present recommended, but a considerable quantity of this insecticide is used each season in controlling the aphid.

The hickory shuckworm occurs in practically every section of the pecan belt. Mining or tunneling of the shucks often results in the improper development of the nut kernels and prevents the natural separation of the shucks from the nutshells. Nuts infested by the shuckworm are often undersized and are usually later in maturing than are those that are free from this pest. The damage is not restricted entirely to the matured nuts, for in the spring and early summer the larvæ destroy the small, green nuts by eating out the interior. Injury of this type is not so noticeable as that caused in the fall, but it should not be minimized, since investigations have shown that it plays no small part in the reduction of the nut crop. Since the insects pass the winter as larvæ in the shucks, one means of aiding control is to gather and destroy all shucks during or immediately after harvest. Some pecan growers use sheets for harvesting their crop; in so doing the shucks are conveniently piled on the sheet and are later removed from the grove and destroyed. As yet no satisfactory spraying method for shuckworm has been devised.

YIELD OF PECANS

Economical yields are the basis of successful crop production and should be the goal of every orchardist. Unlike annual crops, pecan trees can not be taken on trial and then easily discontinued if the results do not meet expectations. Since a pecan orchard represents a considerable investment and requires a number of years of care before giving any return, it is especially important that it be so set and cared for that it will produce enough nuts to return a profit to the grower. Pecan yields, however, are so highly uncertain that the grower may have serious financing problems.

There has been, and still is, much misunderstanding about the yields reasonably to be expected from pecan orchards. The phenomenal yield from some individual tree is frequently used in estimating the potential returns from a prospective orchard. For example, individual old trees, having the advantage of unusually favorable growing conditions, have been known to yield in excess of 500 pounds of nuts in a single year. The enthusiastic planner, hearing of such yields from a single tree, is prone to think that an extensive commercial orchard, producing nuts in proportion to the model tree according to its age, would be a good thing to own. As trees planted in orchards rarely yield in proportion to isolated trees under higher favorable environment, one should not be misled by taking such individual tree records as a basis for estimating probable returns from commercial plantings. Rather, a person who contemplates setting out a pecan orchard and who wishes to estimate his potential returns should note, if possible, the results being obtained from well-cared-for orchards of fairly good size in the community in which he contemplates planting.

There is a wide range in yields, not only between orchards of different ages but also between orchards falling in the same age group. (Table 13.)

TABLE 13.—*Distribution of blocks of pecan trees by age, and by yield per acre, 1928* [1]

Range in yield per acre (pounds)	Distribution of blocks of trees—														
	5–9 years old			10–14 years old			15–19 years old			20–24 years old			25 years old and over		
	Number	*Per cent*	*Acres*	*Number*	*Per cent*	*Acres*	*Number*	*Per cent*	*Acres*	*Number*	*Per cent*	*Acres*	*Number*	*Per cent*	*Acres*
No yield	7	21.9	375	1	2.3	2									
1–10	9	28.1	3,255	1	2.3	45	2	2.7	83						
11–60	7	21.9	1,130	12	27.9	961	11	14.7	1,051	1	3.4	3	2	11.7	47
61–110	6	18.8	266	10	23.3	1,406	10	13.3	260	2	6.9	303			
111–160				5	11.6	192	9	12.0	1,893	3	10.4	82	1	5.9	135
161–210	1	3.1	47	4	9.3	283	11	14.7	259	3	10.4	31	1	5.9	20
211–260	1	3.1	10	2	4.7	58	5	6.7	154	3	10.4	13			
261–310	1	3.1	12	3	7.0	23	6	8.0	540	5	17.2	754	2	11.8	212
311–360				4	9.3	64	8	10.6	152	2	6.9	70	2	11.8	32
361–410							4	5.3	73	5	17.2	53	1	5.9	1
411–460							5	6.7	50						
461–510							1	1.3	9	1	3.4	(2)	4	23.5	68
511–560				1	2.3	6	1	1.3	2	1	3.4	110	1	5.9	38
561–610															
611 and over							2	2.7	3	3	10.4	14	3	17.6	15
Weighted average yield per acre	*Pounds* 12			*Pounds* 101			*Pounds* 145			*Pounds* 320			*Pounds* 330		

[1] For a total of 169 blocks of trees on which data were complete.

[2] Less than 1 acre.

Pecan trees may bear a few nuts when 3 to 5 years of age but, generally speaking, orchards do not come into commercial bearing until they are at least 10 years old. With proper care the trend in yields is then upward as the orchard increases in age. This increase is by no means a fixed ratio, as yields depend not only on the age of the trees but on the soil, climatic conditions, variety, planting distance, and system of orchard management followed.

TABLE 14.—*Yield per acre of 38 individual pecan orchards for which data were complete for either four or five years, 1924–1928* [1]

State, and district	Orchard	Trees set per acre	Age of orchard in 1928	Yield per acre					
				1928	1927	1926	1925	1924	Average
Georgia:		*Number*	*Years*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Albany	1	20	18	167	150	165	185	80	149
Do	2	20	15–19	90	48	207	260	0	121
Do	3	26	18–20	279	126	407	36	0	170
Do	4	20	16	147	104	53	106	0	82
Thomasville	5	17	18	194	94	62	16	16	76
Florida:									
Monticello	6	12	15	72	11	111	83	56	67
Do	7	17	15	100	100	150	110	(2)	[3] 115
Do	8	17	18	460	720	640	600	560	596
Do	9	17	15–19	48	120	48	112	100	86
Eastern	10	17	16	200	17	117	50	67	90
Do	11	27	16	594	562	125	250	(2)	[3] 383
Do	12	27	16–20	188	112	225	125	150	160
Do	13	48	17	571	143	286	143	143	257
Do	14	21	15–18	88	53	59	41	12	51
Do	15	17	18	260	200	509	400	300	334
Do	16	17	15	265	135	77	192	(2)	[3] 167
Do	17	17	15	83	27	40	67	53	54
Do	18	24	15	400	40	160	100	200	180
Alabama:									
Mobile	19	20	15–18	302	0	0	225	(2)	[3] 132
Do	20	17	18	438	0	0	225	(2)	[3] 166
Do	21	15	15	326	0	0	82	44	90
Do	22	22	18	585	0	0	425	75	217
Selma	23	17	15	214	107	236	164	(2)	[3] 180
Do	24	12	18	220	20	500	70	(2)	[3] 202
Do	25	17	18–19	67	3	0	0	(2)	[3] 18
Eufaula	26	8	16	114	86	71	57	34	72
Mississippi:									
Gulf coast	27	17	17	32	0	0	29	(2)	[3] 15
Do	28	12	18	620	0	20	200	(2)	[3] 210
Do	29	17	15–19	35	0	0	140	0	35
Do	30	17	15	17	0	0	6	(2)	[3] 6
Do	31	17	16	130	56	6	3	(2)	[3] 49
Do	32	15	18	229	80	11	169	(2)	[3] 122
Do	33	48	16	1,825	50	0	750	(2)	[3] 656
Do	34	17	18	125	0	0	75	90	58
Do	35	17	15	52	1	0	111	(2)	[3] 41
Do	36	12	18	553	0	344	31	344	254
Louisiana:									
Shreveport	37	14	19	20	40	30	6	8	21
Do	38	12	16	70	0	299	63	90	104
Average				268	84	130	150	[4] 105	

[1] The 1928 yields of pecans for a majority of these selected orchards were considerably higher than the average yield of all orchards studied.
[2] Data not available.
[3] 4-year average.
[4] Average of 23 orchards for which data were available.

Yields per acre of 38 individual pecan orchards for the years 1924–1928 are shown in Table 14. Although the quality of most of these orchards was decidedly better than average, the yield figures serve as illustrations of variations in production from orchard to orchard and from year to year. The variation in yield of a single orchard over a period of years may be as wide as the variation between individual orchards during a single year. Although few of the orchards shown had consistently high yields, a large proportion had relatively good

production over a period of years. The extent to which the use of better cultural practices may eliminate the uncertainty of obtaining uniformly good yields still remains to be seen.

COST OF DEVELOPING PECAN ORCHARDS AND COST OF OPERATING BEARING ORCHARDS, BY DISTRICTS

The general practice of orchard development is somewhat similar in all districts, in so far as the growing of interplanted field crops for harvest is concerned, except in the Gulf coast district of Mississippi and the Mobile district of Alabama. Interplanted crops are grown for feed and for the purpose of deriving some cash income from the orchard while the trees are still in the development stage. In the Mobile district a filler crop of Satsuma oranges is common. Along the Mississippi Gulf coast interplanted crops for harvest are not commonly grown in young orchards.

After the pecan orchard comes into commercial bearing the interplanting of field crops for harvest is discontinued in most districts and pecan production is then given the entire consideration. The exceptions are the Mobile district of Alabama, where the growing of Satsuma oranges is commonly continued in the bearing orchards, and the Shreveport district of Louisiana, where interplanted farm crops for harvest are commonly grown in bearing orchards.

The total cost of developing a pecan orchard into bearing shows considerable variation as between districts. This variation is due to a number of factors such as wages of man labor, horse-work rates, and use of fertilizer. The greatest single factor in the following cost figures is the amount of the joint costs that are charged to pecans. The cost of bringing a pecan orchard into bearing along the Mississippi Gulf coast, the one district where interplanted crops for harvest are not common, was much higher than in any other district.

The pecan tree requires a fertile, productive soil; if intercropping is practiced to offset to some extent the expense during the development period, a proper rotation of crops with frequent use of legumes should be followed, together with the use of generous applications of commercial fertilizer. The idea is not only to maintain the fertility of the soil, but also gradually to build it up and put it in condition to produce large yields of pecans.

The ultimate object is a healthy, normal orchard, and if this development is not unduly hindered by growing interplanted crops for harvest, and if a pecan grower is in a position to use to advantage the products produced in the orchard, or if he can find a ready sale at a profit for these products, he may well reduce production costs to a minimum by following the practice during the first few years or until the additional space is needed for the future well-being of the orchard.

The present tendency to set pecan trees greater distances apart than was the practice during the early years of the industry is a further reason why interplanting during the development period may be practiced without serious detrimental effects. Care should be exercised in not growing other crops too close to the pecan trees.

Cost of production per acre previous to harvest is a more stable figure than the cost of production per pound of nuts. Irrespective of whether a crop is produced, the orchard receives a certain amount of care, which in many cases does not differ materially from year to

year. Provided the general system of management remains constant, the cost per acre previous to harvest will differ only slightly from year to year except as changes occur in the prices paid for labor, power, and materials.

The total cost of production per acre and per pound takes into consideration the cost of harvesting and delivering the nuts to the shipping point and varies largely with the yield. During the year of this study (1928) conditions were relatively favorable for pecan production. Obviously the yields for that year do not represent a fair basis in all cases for calculating production costs per pound of nuts. Nor was it possible to obtain reliable yield data for a series of years for all orchards. For these reasons the cost figures given are on an acre basis; with them are given the yields that are necessary to pay production costs, if the nuts are sold at State average prices received by growers in 1928.

The following text and tables briefly summarize practices and costs of developing a pecan orchard to commercial bearing age and the annual cost of operating an orchard of bearing age, for each of the districts studied. In considering these costs, the reader should keep in mind that a considerable portion of the cost of developing an orchard and of producing pecans may not represent an actual out-of-pocket cost. In many instances, much of the labor is performed by the pecan grower and his family. On farms where there are enterprises other than pecans, much of the additional labor and use of implements and work stock, made necessary because a pecan orchard is being developed, and later is cared for in its bearing stage, represents additional use of these things not provided for by other farm enterprises and hence is not additional actual cost to the farmer. The purchase price of the land itself is, of course, to be considered as a significant part of the initial cost of development and operation of bearing pecan orchards.

These considerations are of prime importance to those who contemplate the development of a pecan orchard. In most cases the man who can develop and operate an orchard to best advantage and at lowest significant cost is the one who does it as a part of his own farming business. The contrary is true of orchards under the management of caretakers where the operations are commonly performed at contract rates. In such cases, the total cost of developing and operating the orchard, aside from the use of land, normally represents an actual cash outlay.

GEORGIA

ALBANY DISTRICT

The majority of the orchards studied in the Albany district of Georgia are in Dougherty County; others studied are in the counties of Lee and Mitchell. In this district farm crops for harvest are usually interplanted in young orchards, but a free space is allowed on each side of the tree rows. These tree-row spaces have a total width of approximately 12 feet for the first 4 years and 20 feet for the next 6 years and are cultivated independently of the interplanted crop. In the spring the tree-row space is plowed. The remainder of the orchard acreage is plowed and planted to field crops. Following an application of fertilizer in the spring, the tree rows are clean

cultivated about six times during the remainder of the season. One-horse cultivators are used for cultivating close to the trees. The rest of the tree-row space is cultivated with disk harrows. Although cover crops are used in some of the young orchards in the district, the practice is not common. Little spraying or dusting is done. Horses or mules are usually used to furnish motive power in orchards that are intercropped. During the first 10 years of growth a total of about 132 man hours and 119 horse hours are used to plant and fertilize the trees, cultivate the tree-row spaces, and prune and care for the trees. At rates prevailing in 1928, the labor and power cost for the first 10 years amounted to about $31 an acre. (Table 15.)

TABLE 15.—*Georgia, Albany district: Labor and power cost per acre of developing a pecan orchard during the first 10 years, according to a common method* [1] *and at cost rates prevailing in 1928*

Operation	Years operation is performed	Size of crew		Rate of work per day	Times done each year	Percentage charged to pecans	Charged to pecans		Cost
		Men	Horses				Man labor	Horse work	
		Number	*Number*	*Orchard acres*	*Number*	*Per cent*	*Hours*	*Hours*	*Dollars*
Plow	First to fifth	1	2	2	1	25	5.0	10.0	1.62
	Fifth to tenth	1	2	2	1	42	12.6	25.2	4.10
Plant:									
Lay off rows	First	1	1	30	1	100	.3	.3	.07
Set stakes	do	3	--	35	1	100	.9	-------	.11
Dig holes	do	1	---	1.5	1	100	6.7	-------	.84
Set trees	do	7	2	12	1	100	5.8	1.7	.90
Apply fertilizer around trees	First and second	3	2	30	1	100	2.0	1.4	.39
	Third	3	2	24	1	100	1.2	.8	.23
	Fourth	3	2	20	1	100	1.5	1.0	.29
	Fifth and sixth	3	2	17	1	100	3.5	2.4	.68
	Seventh to tenth	3	2	14	1	100	8.4	5.6	1.61
Cultivate tree rows	First to tenth	1	1	30	6	100	20.0	20.0	4.50
	First to fourth	1	3	30	3	100	4.0	12.0	1.70
	Fifth to tenth	1	3	18	3	100	10.2	30.6	4.34
Hoe around trees	First and second	1	-------	20	2	100	2.0	-------	.25
	Third to fifth	1	-------	18	2	100	3.3	-------	.41
	Sixth to tenth	1	-----	15	2	100	6.5	-------	.81
Prune	Second to tenth	-----	------	--------	-------	100	5.7	-------	.71
Remove pruned wood	Sixth to tenth	-----	-------	--------	-------	100	3.2	3.2	.72
Supervision	First to tenth	-----	-------	--------	-------	100	22.0	-------	5.50
Miscellaneous [2]	do	---	------	--------	-------	100	7.0	4.5	1.32
Total	------	------	-------	--------	-------	-------	131.8	118.7	31.10

[1] Trees set 46⅔ by 46⅔ feet, or 20 to the acre. Tree-row spaces have a total width of about 12 feet for the first 4 years and 20 feet for the next 6 years. Tree-row spaces cultivated independently, rest of space cropped in cotton or other cultivated crop for harvest.

[2] Includes manuring, spraying, seeding cover crop, orchard sanitation, and replacing missing trees.

In 1928 pecan-orchard land was valued at about $30 an acre. Trees for planting 46 feet 8 inches each way cost $12 an acre (20 trees at 60 cents each). The cost of trees, labor and power, fertilizer, taxes, interest, and other items chargeable to the trees plus the value of land on which the trees were set amounted to about $52 an acre for the first year. After the first year, the annual cost increased from about $7 an acre in the second year to almost $20 an acre in the tenth year. At the end of 10 years, the total cost, including interest on the investment compounded annually, and $30 for land amounted to $166.32 an acre. (Table 16.)

TABLE 16.—*Georgia, Albany district: Cost per acre of developing a pecan orchard for the first 10 years, by years, according to a common method and at cost rates prevailing in 1928*

Item	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	Ninth year	Tenth year
Fertilizer—pounds	40	60	80	120	160	160	200	200	200	200
Labor and power:										
Man labor—hours	24.7	9.0	9.4	11.2	12.1	12.6	13.2	13.4	13.0	13.2
Horse work—do	10.5	8.5	8.5	9.8	12.8	13.5	13.6	13.9	13.7	13.9
Labor and power:	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
Man labor [1]	3.60	1.31	1.38	1.64	1.76	1.83	1.93	1.95	1.90	1.93
Horse work at 10 cents per hour	1.05	.85	.85	.98	1.28	1.35	1.36	1.39	1.37	1.39
Total	4.65	2.16	2.23	2.62	3.04	3.18	3.29	3.34	3.27	3.32
Materials:										
Trees at 60 cents each	12.00									
Fertilizer at $30 per ton	.60	.90	1.20	1.80	2.40	2.40	3.00	3.00	3.00	3.00
Miscellaneous [2]	.46	.92	.92	.19	.40	.52	.91	1.17	2.08	3.09
Total	13.06	1.82	2.12	1.99	2.80	2.92	3.91	4.17	5.08	6.09
Other costs:										
Taxes [3]	.31	.31	.31	.31	.52	.52	.52	.52	.52	.52
Use of machinery [4]	.39	.32	.32	.37	.48	.51	.51	.59	.51	.52
Overhead [4]	2.66	.60	.65	.69	.88	.92	1.08	1.13	1.25	1.41
Total	3.36	1.23	1.28	1.37	1.88	1.95	2.11	2.24	2.28	2.45
Total cost, exclusive of interest	21.07	5.21	5.63	5.98	7.72	8.05	9.31	9.75	10.63	11.86
Interest at 6 per cent [3 4]	.57	1.84	2.27	2.76	3.62	4.31	5.05	5.95	6.85	7.91
Total cost	21.64	7.05	7.90	8.74	11.34	12.36	14.36	15.70	17.48	19.77
Cost of development at end of each year [5]	51.64	58.69	66.59	75.33	86.67	99.03	113.39	129.09	146.57	166.34

[1] Ordinary labor charged at 12½ cents per hour, supervision at 25 cents per hour.
[2] Includes manure, spray material, cover-crop seed, replants, and other materials.
[3] Charges for taxes and interest prorated to pecan trees as follows: First 4 years, 25 per cent, next 6 years, 42 per cent.
[4] See p. 16 for method of computing machinery, overhead, and interest charges.
[5] Total cost including interest plus inititial value of land, at $30 an acre.

The growing of field crops for harvest in the orchard is usually discontinued when the young orchards come into commercial bearing, and more attention is given to soil improvement through the use of cover crops. In bearing orchards of the Albany district a winter cover crop, usually Austrian winter peas, is seeded in the fall. This is plowed under during the following spring. Commercial fertilizer is then spread around the trees and worked in with a disk harrow. A summer cover crop of velvetbeans is then drilled, but enough free space is left on each side of the tree rows to permit cultivation next to the trees. This space is gone over with a disk harrow during the summer. The velvetbeans are disked under in the fall, thus clearing the land for harvest and preparing the soil for the winter cover crop.

The care of an acre of bearing orchard in the Albany district usually takes slightly more than an equivalent of two days of man labor per year, and the necessary motive power for performing the field operations. Since field crops are not commonly grown in bearing orchards, and the pecan acreage under one management is usually large, tractors are well adapted for use in this district.

TABLE 17.—*Georgia, Albany district: Annual labor and power cost per acre, of operating pecan orchards 15 to 19 years old* [1] *up to harvest time, according to a common method and at cost rates prevailing in 1928* [2]

Operation	Size of crew			Rate of work per day	Times done	Man labor	Horse work	Tractor work	Cost
	Men	Horses	Tractor						
	Number	*Number*	*Number*	*Orchard acres*	*Number*	*Hours*	*Hours*	*Hours*	*Dollars*
Prune	2			12	1	1.7			0.21
Remove pruned wood	2	2		30	1	.7	0.7		.16
Orchard sanitation						4.7	.8		.67
Plow	1	2		2	1	5.0	10.0		1.62
Apply fertilizer around trees	5	2		20	1	2.5	1.0		.41
Disk harrow	1		1	25	1	.4		0.4	.55
Seed summer cover crop	1		1	30	1	.3		.3	.41
Cultivate tree rows (disk harrow)	1		1	50	2	.4		.4	.55
Disk under summer cover crop	1		1	30	2	.7		.7	.96
Seed winter cover crop	1		1	30	1	.3		.3	.41
Supervision						3.5			.88
Miscellaneous [3]						1.0	.6		.19
Total						21.2	13.1	2.1	7.02

[1] Trees set 46⅔ by 46⅔ feet, or 20 to the acre, of which 3 per cent were missing, 86 per cent were in bearing, and 11 per cent not in bearing—mainly replants.
[2] Ordinary labor at 12½ cents an hour, supervision at 25 cents, horse work at 10 cents and use of tractor at $1.25.
[3] Includes hoeing, applying manure, spraying, and miscellaneous operations.

The cost of labor, materials, etc., per acre in 1928 is shown in Tables 17 and 18.

TABLE 18.—*Georgia, Albany district: Annual cost per acre of operating pecan orchards 15 to 19 years old,*[1] *according to a common method and at cost rates prevailing in 1928, and yield required to cover costs*

Item	Quantity	Cost
Labor and power prior to harvest:		
Man labor	*Hours* 21.2	*Dollars* 3.09
Horse work	13.1	1.31
Tractor work	2.1	2.62
Total		7.02
Materials:		
Fertilizer, at $30 per ton	*Pounds* 388.0	5.82
Summer cover crop, velvetbeans, at $1.50 per bushel	*Bushels* 0.75	1.12
Winter cover crop, Austrian winter peas, at 9 cents per pound	*Pounds* 30.00	2.70
Miscellaneous [2]		1.65
Total		11.29
Other costs:		
Taxes		1.25
Use of machinery, not including tractor [3]		.62
Overhead [3]		2.75
Total		4.62
Total cost, exclusive of interest		22.93
Interest at 6 per cent [3]		10.18
Total cost		33.11
Quantity of nuts, at 28 cents per pound,[4] required to cover cost, including harvesting:		
Exclusive of interest	93	
Inclusive of interest	133	

[1] Trees set 46⅔ by 46⅔ feet or 20 to the acre, of which 3 per cent were missing, 86 per cent were in bearing, and 11 per cent not in bearing—mainly replants.
[2] Includes manure, spray material, and other materials.
[3] See page 16 for method of computing machinery, overhead, and interest charges.
[4] The 1928 State average farm price. Harvesting costs includes picking, grading, and delivery to local shipping point and are based on pecans sold through a cooperative association.

Harvesting costs in 1928 ranged from about $2 to $4 per hundred pounds of nuts, depending largely on the yield.

The 1928 pecan yields in Georgia were considerably above the average for other seasons (Table 8), but many of the orchards 15 to 19 years of age in the Albany district did not have yields sufficient to cover costs as computed in this bulletin. Production records obtained through personal visits and through the use of mailed questionnaires furnished yield information on a tree basis for 36 orchards, representing a total of 72,832 trees 15 to 19 years of age. The distribution of orchards according to the average tree yield in 1928 is shown below:

Yield per tree, in pounds	Number of orchards	Yield per tree, in pounds	Number of orchards
1–3.9	9	20–23.9	0
4–7.9	12	24–27.9	0
8–11.9	5	28–31.9	1
12–15.9	4	32–35.9	2
16–19.9	2	36 and over	1

The exceptionally high-yielding orchards are relatively few in number. The majority of the orchard owners reported yields under 8 pounds a tree, as indicated in the distribution shown. On an acre basis, allowing 20 trees to the acre and assuming that 86 per cent of the trees are in production, approximately 53 per cent of the entire group of orchards failed to produce enough nuts in the good season of 1928 to cover the costs, including harvesting and interest charges. (Table 18.) Excluding interest, 36 per cent of the orchards did not have yields sufficient to cover costs.

Orchard management is an especially important factor in the Albany district because of the large holdings under the management of individuals. The test of successful orchard management is measured by ability to realize profitable yields in return for the outlay of capital and labor and the use of land. Some of the orchards studied produced profitable yields in 1928, while others did not.

Either singly or in combination, several factors other than management may affect yields adversely. A mistaken impression of the length of time required for a young orchard to come into commercial bearing has often resulted in inadequate provision being made at the outset for financing the enterprise, with a consequent neglect of the orchard during the later part of the development period. In some cases it has been difficult to overcome this imposed handicap, except at the expense of a delayed bearing period or even partial replanting of portions of the orchard.

Location of the orchard with respect to the ability of the soil to meet, or be made to meet economically, the plant-food requirements of pecan trees is one of the most essential factors in determining the future profitableness of the orchard. The turning under of leguminous cover crops and the use of commercial fertilizers have been profitably practiced in many of the more successful, established orchards.

THOMASVILLE DISTRICT

The orchards studied in the Thomasville district are in Thomas and Grady Counties, with the majority in the former county. The common system of orchard development is similar to that of the Albany district. Field crops for harvest (principally cotton, corn, and pea-

nuts) are usually interplanted in the young orchards during the entire development period. Cultivated spaces are provided on each side of the tree rows. These tree-row spaces have a total width of approximately 16 feet for the first five years of the development period and 24 feet for the next five years, and are cultivated independently of the interplanted crop.

In the spring the orchard acreage is plowed and planted to field crops for harvest, except the spaces along the tree rows. Fertilizer is applied around the trees and is worked in with disk harrows. During the summer, the tree rows are given clean cultivation. Cover crops are planted in strips along the tree rows in some of the orchards, but the practice is not common. Little spraying or dusting is done. Horses or mules are the common source of motive power in developing young orchards in this district chiefly because of the common practice of growing row crops for harvest.

The costs during the development period are shown in Table 19.

TABLE 19.—*Georgia, Thomasville district: Labor and power costs per acre of developing a pecan orchard during the first 10 years, according to a common method* [1] *and at cost rates prevailing in 1928*

Operation	Years operation is performed	Size of crew		Rate of work per day	Times done each year	Percentage charged to pecans	Charged to pecans		Cost
		Men	Horses				Man labor	Horse work	
		Number	*Number*	*Orchard acres*	*Number*		*Hours*	*Hours*	*Dollars*
Plow	First to fifth	1	2	1.5	1	27	9.0	18.0	3.60
	Sixth to tenth	1	2	1.5	1	40	13.5	27.0	5.40
Plant:									
Set stakes	First	3		24	1	100	1.2		.18
Dig holes	do	1		3	1	100	3.3		.50
Set trees	do	3	2	12	1	100	2.5	1.7	.59
Apply fertilizer around trees	do	3	2	45	1	100	.6	.4	.14
	Second	3	2	40	1	100	.8	.5	.18
	Third and fourth	3	2	35	1	100	1.8	1.2	.42
	Fifth and sixth	3	2	30	1	100	2.0	1.4	.48
	Seventh	3	2	25	1	100	1.2	.8	.28
	Eighth and ninth	3	2	20	1	100	3.0	2.0	.70
	Tenth	3	2	18	1	100	1.7	1.1	.39
Cultivate tree rows	First to fifth	1	3	25	5	100	10.0	30.0	5.25
	Sixth to tenth	1	3	20	5	100	12.5	37.5	6.56
Hoe around trees	First	1		25	2	100	.8		.12
	Second	1		20	2	100	1.0		.15
	Third and fourth	1		18	2	100	2.2		.33
	Fifth	1		16	2	100	1.2		.18
	Sixth and seventh	1		15	2	100	2.6		.39
	Eighth	1		14	2	100	1.4		.21
	Ninth and tenth	1		12	2	100	3.2		.48
Prune	Second to tenth					100	4.9		.74
Remove pruned wood	Sixth to tenth					100	3.5	3.5	.96
Supervision	First to tenth					100	20.0		6.00
Miscellaneous [2]	do					100	15.9	8.3	3.42
Total							119.8	133.4	37.65

[1] Trees set 60 by 60 feet, or 12 to the acre. Tree-row spaces have a total width of 16 feet for the first 5 years and 24 feet for the next 5 years. Tree-row spaces are cultivated independently; rest of space is cropped in cotton or other cultivated crop for harvest.

[2] Includes spraying, seeding winter and summer cover crop, orchard sanitation, and replacing missing trees.

The distance of planting pecan trees as well as the practice of interplanting field crops for harvest in the orchards may well be discussed in conjunction with soil fertility. The planting of trees at distances of 46⅔ by 46⅔ feet, or 20 trees to the acre, is a common practice in the area. The consensus of opinion among the better orchardists at present, based on their past experience, is that a smaller number of

trees per acre would permit a better growth of the individual trees, with a better future development of the orchard. A greater opportunity also would be given to realize an income from interplanted crops pending the development of the young orchard into commercial bearing. With the interplanting of crops for harvest, especial attention should be given to the maintenance and possibly the upbuilding of soil fertility to provide for the plant-food requirements of the trees and the interplanted crop.

Choice of suitable varieties should be given careful consideration at planting time in obviating, in so far as possible, the expensive necessity of top-working the trees later. Top-working is not only expensive in itself, but it also seriously curtails yields for six to eight years.

Some grazing of orchards is done in the area, but the returns from orchards so handled do not equal those from orchards in which a well-planned system of soil management is practiced and measures taken to control insects and diseases.

Much of the discussion of factors that affect yields applies with equal force to the other districts included in this study. In the ensuing discussions of the separate districts, then, only the factors that are of particular importance in each district are discussed.

In 1928 pecan orchard land was valued at about $40 an acre. At the end of 10 years the total cost, including interest compounded annually and $40 for land, amounted to $176 an acre. (Table 20.)

TABLE 20.—*Georgia, Thomasville district: Cost per acre of developing a pecan orchard for the first 10 years, by years, according to a common method and at cost rates prevailing in 1928*

Item	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	Ninth year	Tenth year
Fertilizer—pounds	24	36	60	60	84	84	96	120	120	120
Labor and power:										
Man labor—hours	15.7	8.3	8.5	9.8	9.0	11.8	12.5	14.3	15.0	14.9
Horse work—do	12.2	10.5	10.6	11.8	10.7	14.9	14.9	15.8	15.9	16.1
Labor and power:	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
Man labor [1]	2.75	1.45	1.49	1.71	1.58	2.07	2.19	2.50	2.62	2.61
Horse work at 12½ cents per hour	1.53	1.31	1.32	1.48	1.34	1.86	1.86	1.98	1.99	2.01
Total	4.28	2.76	2.81	3.19	2.92	3.93	4.05	4.48	4.61	4.62
Materials:										
Trees at $1 each	12.00									
Fertilizer at $30 per ton	.36	.54	.90	.90	1.26	1.26	1.44	1.80	1.80	1.80
Miscellaneous [2]	.60	.75	.92	.88	.65	.70	.91	1.17	2.06	2.12
Total	12.96	1.29	1.82	1.78	1.91	1.96	2.35	2.97	3.86	3.92
Other costs:										
Taxes [3]	.34	.34	.34	.34	.34	.50	.50	.50	.50	.50
Use of machinery [4]	.46	.39	.40	.44	.40	.56	.56	.59	.60	.60
Overhead [4]	2.59	.61	.69	.75	.72	.88	.96	1.12	1.27	1.28
Total	3.39	1.34	1.43	1.53	1.46	1.94	2.02	2.21	2.37	2.38
Total cost, exclusive of interest	20.63	5.39	6.06	6.50	6.29	7.83	8.42	9.66	10.84	10.92
Interest at 6 per cent [3 4]	.79	2.05	2.50	3.03	3.58	4.54	5.28	6.11	7.06	8.13
Total cost	21.42	7.44	8.56	9.53	9.87	12.37	13.70	15.77	17.90	19.05
Cost of development at end of each year [5]	61.42	68.86	77.42	86.95	96.82	109.19	122.89	138.66	156.56	175.61

[1] Ordinary labor charged at 15 cents per hour, supervision at 30 cents per hour.
[2] Includes spray material, cover-crop seed, replants, and other materials.
[3] Charges for taxes and interest prorated to pecan trees as follows: First 5 years, 27 per cent; next 5 years, 40 per cent.
[4] See p. 16 for method of computing machinery, overhead, and interest charges.
[5] Total cost including interest plus initial value of land, at $40 an acre.

Growing of interplanted crops for harvest is not common in bearing orchards of this district, more attention being given to soil improvement through the use of cover crops. In the fall a cover crop, usually Austrian winter peas and rye, is drilled in. The following spring, fertilizer is broadcast by hand on top of the cover crop around the trees and is then plowed under. During the summer, clean cultivation is given with a disk harrow; the last cultivation serves to clear the land for harvest and to prepare the soil for the winter cover crop. Spraying or dusting and the planting of a summer cover crop of velvetbeans are done in a few of the orchards but these operations are not common. The practice of clean cultivation in bearing orchards is a large factor in making tractors adapted for tillage operations in this district. The labor and power cost, at prevailing rates in 1928, not including harvest, amounting to about $12 an acre is shown in Table 21.

TABLE 21.—*Georgia, Thomasville district: Annual labor and power cost per acre of operating pecan orchards 15 to 19 years old [1] up to harvest time, according to a common method and at cost rates prevailing in 1928 [2]*

Operation	Size of crew			Rate of work per day	Times done	Man labor	Horse work	Tractor work	Cost
	Men	Horse	Tractor						
	Number	*Number*	*Number*	*Orchard acres*	*Number*	*Hours*	*Hours*	*Hours*	*Dollars*
Prune	2			10	1	2.0			0.30
Remove pruned wood	2	2		18	1	1.1	1.1		.30
Orchard sanitation						2.0	1.1		.44
Apply fertilizer around trees	4	2		18	1	2.2	1.1		.47
Plow	1	2		1.5	1	6.7	13.4		2.68
Cultivate:									
Disk-harrow, double cut	1		1	15	3	2.0		2.0	2.80
Disk-harrow, single cut	1		1	28	3	1.1		1.1	1.54
Drill winter cover crop	1		1	15	1	.7		.7	.98
Supervision						4.1			1.23
Miscellaneous [3]						2.6	3.5	.2	1.08
Total						24.5	20.2	4.0	11.82

[1] Trees set 60 by 60 feet, or 12 to the acre, of which 6 per cent were missing, 90 per cent were in bearing, and 4 per cent were not in bearing—mainly replants.

[2] Ordinary labor at 15 cents an hour, supervision at 30 cents, horse work at 12½ cents, and use of tractor at $1.25.

[3] Includes applying manure, hoeing, spraying, hauling fertilizer, and miscellaneous operations.

The total 1928 operating cost is shown in Table 22. Harvest costs varied from $1.50 to $3.50 per hundred pounds of nuts, depending largely on the yield obtained.

The bearing orchards from which cultural practices and production data were secured reported yields which were more than sufficient to cover the costs of production indicated in Table 22. The yields reported from orchards 15 to 19 years of age in 1928 ranged from 157 pounds to 543 pounds to the acre, with higher yields reported for older orchards. These favorable yields may be attributed primarily to the system of orchard management practiced in the area.

Enlarging the area under consideration by the inclusion of yield data obtained from southwest Georgia, of which the Thomasville district is a part, indicates that comparably favorable yields were not obtained in 1928 from any great portion of the more numerous orchards included in the broader area. This phase of the survey shows that 396,040 trees of improved varieties, 10 years old and over,

produced an average of 6.78 pounds of pecans a tree. On the basis of 12 trees to the acre, of which 10.8 are assumed to be in bearing, this would represent a yield of approximately 73 pounds of nuts an acre. In considering the wider area in its entirety, the average yields obtained, selling at 1928 prices, were not sufficient to cover operating costs, including interest and harvesting charges, computed on the basis of the most common practices followed in the district. This was in a year when pecan yields were relatively high. (Table 8.)

TABLE 22.—*Georgia, Thomasville district: Annual cost per acre of operating pecan orchards 15 to 19 years old,*[1] *according to a common method and at cost rates prevailing in 1928, and yield required to cover costs*

Item	Quantity	Cost
Labor and power prior to harvest:	*Hours*	*Dollars*
Man labor	24.5	4.29
Horse work	20.2	2.53
Tractor work	4.0	5.00
Total		11.82
Materials:	*Pounds*	
Fertilizer, at $30 per ton	338.0	5.07
Winter cover crop, Austrian winter peas, at 8 cents per pound	20.0	1.60
	Bushel	
Rye, at $2.50 per bushel	0.5	1.25
Miscellaneous [2]		1.19
Total		9.11
Other costs:		
Taxes		1.25
Use of machinery, not including tractor [3]		.89
Overhead [3]		3.14
Total		5.28
Total cost exclusive of interest		26.21
Interest, at 6 per cent [3]		10.82
Total cost		37.03
Quantity of nuts, at 28 cents per pound,[4] required to cover cost including harvesting:	*Pounds*	
Exclusive of interest	105	
Inclusive of interest	145	

[1] Trees set 60 by 60 feet, or 12 to the acre, of which 6 per cent were missing, 90 per cent were in bearing, and 4 per cent were not in bearing—mainly replants.
[2] Includes spray material, paint, manure, and other materials.
[3] See p. 16 for method of computing machinery, overhead, and interest charges.
[4] The 1928 State average farm price. Harvesting costs include picking, grading, and delivery to local shipping points, and are based on pecans sold through a cooperative association.

A consideration of the natural factors of soils, topography, and climate does not indicate that the Thomasville district enjoys a greater comparative advantage in pecan production than the larger area of which it is a part, therefore the grouping of the orchards studied in the Thomasville district into the higher-yield range may be attributed largely to the greater degree of uniformity in successful orchard management practiced on these orchards.

Yield data from older orchards in the area indicate the possibilities resulting from the application of orcharding principles which take into consideration the fundamental factors affecting successful production. This may be illustrated by outlining briefly the system used on, and the results obtained from, an orchard 21 years old. The greater proportion of the trees were of the Frotscher, Moneymaker, and Stuart varieties. The cultural practices followed were similar, in the main, to those outlined in Table 21, with the exception

that a cover crop of velvetbeans was usually turned under in the late summer of each year. Over a period of five years, from 1924 to 1928, this orchard produced an annual average yield of approximately 420 pounds of pecans an acre. The average yield per acre for each year, beginning in 1924, was 191, 336, 473, 291, and 811 pounds an acre.

These yields are considerably above the average for the orchard yields from the district and are used here to indicate the possible benefits resulting from an intelligently planned and well-executed system of orchard management adapted to the area. Such a system takes into consideration the suitable location of the orchard with respect to soil and topography, the choice of varieties adapted to the area, and the adoption of cultural practices which, in conjunction with soil upkeep and the control of diseases and insect pests, are most likely to result in the securing of economic yields.

FLORIDA

MONTICELLO DISTRICT

The orchards studied in the Monticello district of Florida are all in Jefferson County. The management in this district varies from pasturing livestock in the orchards and leaving the orchards for the most part uncultivated to giving them reasonably good care. Although perhaps a majority of the orchards are receiving indifferent care the cost estimates are for those that are receiving reasonably good attention.

TABLE 23.—*Florida, Monticello district: Labor and power costs per acre of developing a pecan orchard during the first 10 years, according to a common method* [1] *and at cost rates prevailing in 1928*

Operation	Years operation is performed	Size of crew		Rate of work per day	Times done each year	Percentage charged to pecans	Charged to pecans		Cost
		Men	Horses				Man labor	Horse work	
		Number	*Number*	*Orchard acres*	*Number*	*Per cent*	*Hours*	*Hours*	*Dollars*
Plow (spring)	First to sixth	1	2	1.5	1	30	12.0	24.0	4.20
	Seventh to tenth	1	2	1.5	1	40	10.8	21.6	3.78
Harrow (disk)	First to sixth	1	2	8	1	30	2.4	4.8	.84
	Seventh to tenth	1	2	8	1	40	2.0	4.0	.70
Plant:									
Set stakes	First	3		30	1	100	1.0		.15
Dig holes	do	2		7	1	100	2.9		.44
Set trees	do	5	2	14	1	100	3.6	1.4	.68
Cultivate tree rows (disk harrow)	First to sixth	1	2	20	7	100	21.0	42.0	7.35
	Seventh to tenth	1	2	15	7	100	18.8	37.6	6.58
Plow (fall)	First to fifth	1	2	1.5	1	30	10.0	20.0	3.50
	Sixth to tenth	1	2	1.5	1	40	13.5	27.0	4.72
Sow cover crop	First to fifth	1		15	1	30	1.0		.15
	Sixth to tenth	1		15	1	40	1.5		.22
Disk in cover crop	First to fifth	1	2	8	1	30	2.0	4.0	.70
	Sixth to tenth	1	2	8	1	40	2.5	5.0	.88
Supervision	First to tenth					100	27.0		8.10
Miscellaneous [2]	do					100	29.2	11.4	5.52
Total							161.2	202.8	48.51

[1] Trees set 60 by 60 feet, or 12 to the acre. Tree-row spaces have a total width of about 18 feet for the first 6 years and 24 feet for the next 4 years. Tree-row spaces are cultivated independently; rest of space is cropped in corn or other cultivated crop for harvest.

[2] Includes application of fertilizer and manure, spraying, orchard sanitation, pruning, hoeing, and replacing missing trees.

In this class of orchards, farm crops for harvest are grown among the young trees. The common practice is to allow a free space on each side of the tree rows. These tree-row spaces have a total width of approximately 18 feet for the first six years and 24 feet for the next four years and are cultivated independently of the interplanted crop. A winter cover crop usually of oats, rye, Austrian winter peas, or vetch may be planted in the fall and turned under in the spring. During the summer, the tree-row spaces are given clean cultivation with a disk harrow. Neither spraying nor dusting is commonly practiced. Many of the orchards are small and tractor power is not commonly used in this district. The total labor and power cost for the first 10 years are shown in Table 23 and other development costs in Table 24.

TABLE 24.—*Florida, Monticello district: Cost per acre of developing a pecan orchard for the first 10 years, by years, according to a common method and at cost rates prevailing in 1928*

Item	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	Ninth year	Tenth year
Labor and power:										
Man labor---hours	19.7	15.0	14.8	14.9	14.2	15.5	16.8	16.8	16.7	16.8
Horse work---do	18.2	18.0	17.9	18.0	17.9	19.7	23.2	23.2	23.3	23.4
Labor and power:	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
Man labor [1]	3.45	2.62	2.59	2.61	2.49	2.72	2.94	2.94	2.93	2.94
Horse work at 10 cents per hour	1.82	1.80	1.79	1.80	1.79	1.97	2.32	2.32	2.33	2.34
Total	5.27	4.42	4.38	4.41	4.28	4.69	5.26	5.26	5.26	5.28
Materials:										
Trees at $1 each	12.00									
Cover crop seed	.30	.30	.30	.30	.30	.30	.40	.40	.40	.40
Miscellaneous [2]	.33	2.41	2.34	2.52	2.15	2.38	2.31	2.46	2.47	2.60
Total	12.63	2.71	2.64	2.82	2.45	2.68	2.71	2.86	2.87	3.00
Other costs:										
Taxes [3]	.06	.06	.06	.06	.06	.06	.08	.08	.08	.08
Use of machinery [4]	.68	.74	.74	.74	.66	.65	.76	.76	.76	.82
Overhead [4]	2.68	1.07	1.05	1.08	1.01	1.10	1.20	1.22	1.22	1.24
Total	3.42	1.87	1.85	1.88	1.73	1.81	2.04	2.06	2.06	2.14
Total cost, exclusive of interest	21.32	9.00	8.87	9.11	8.46	9.18	10.01	10.18	10.19	10.42
Interest at 6 per cent [3 4]	.65	2.00	2.66	3.35	4.09	4.98	5.87	6.82	7.84	8.95
Total cost	21.97	11.00	11.53	12.46	12.55	14.16	15.88	17.00	18.03	19.37
Cost of development at end of each year [5]	46.97	57.97	69.50	81.96	94.51	108.67	124.55	141.55	159.58	178.95

[1] Ordinary labor charged at 15 cents per hour, supervision at 30 cents per hour.
[2] Includes commercial fertilizer, manure, spray material, trees for replanting, and other materials.
[3] Charges for taxes and interest prorated to pecan trees as follows: First 6 years, 30 per cent; next 4 years, 40 per cent.
[4] See p. 16 for method of computing machinery, overhead, and interest charges.
[5] Total cost including interest plus initial value of land, at $25 an acre.

The practice of growing interplanted crops for harvest is usually discontinued when the young orchards come into commercial bearing. A winter cover crop of oats was used on approximately one-third of the bearing-orchard acreage surveyed. This crop is plowed under in the spring and, following the preparation of the soil with a disk harrow, a summer cover crop of velvet beans is planted in 4-foot rows. This crop, together with the pecan trees, is cultivated during the summer, and just previous to harvest in the fall the summer cover crop is plowed under. The turning under of the summer cover crop

serves as the first step in the soil preparation for the winter cover crop. The labor and power cost, not including harvesting the crop, in the care of a bearing orchard is shown in Table 25 and the total 1928 operating cost in Table 26.

TABLE 25.—*Florida, Monticello district: Annual labor and power cost per acre of operating pecan orchards 15 to 19 years old* [1] *up to harvest time, according to a common method and at cost rates prevailing in 1928* [2]

Operation	Size of crew		Rate of work per day	Times done	Percentage charged to pecans	Charged to pecans		
	Men	Horses				Man labor	Horse work	Cost
	Number	*Number*	*Orchard acres*	*Number*	*Per cent*	*Hours*	*Hours*	*Dollars*
Prune	1		5	1	100	2.0		0.30
Remove pruned wood	1	1	10	1	100	1.0	1.0	.25
Plow	1	2	1.5	1	100	6.7	13.4	2.34
Harrow (disk)	1	2	8	1	100	1.2	2.4	.42
Plant velvetbeans (4-foot rows)	1	1	7	1	100	1.4	1.4	.35
Cultivate tree rows and beans	1	1	5	2	100	4.0	4.0	1.00
Plow (fall)	1	2	1.5	1	33	2.2	4.4	.77
Sow cover crop [3]	1		15	1	33	.2		.03
Disk in cover crop	1	2	8	1	33	.4	.8	.14
Supervision					100	4.4		1.32
Miscellaneous [4]					100	2.9	1.6	.60
Total						26.4	29.0	7.52

[1] Trees set 60 by 60 feet or 12 to the acre, of which 2 per cent were missing, 80 per cent were in bearing, and 18 per cent were not in bearing—mainly replants.
[2] Ordinary labor at 15 cents an hour, supervision at 30 cents, and horse work at 10 cents.
[3] Approximately one-third of the orchard acreage received a winter cover crop of oats.
[4] Includes hoeing, spraying, orchard sanitation, applying manure and commercial fertilizer.

TABLE 26.—*Florida, Monticello district: Annual cost per acre of operating pecan orchards 15 to 19 years old* [1] *according to a common method and at cost rates prevailing in 1928, and yield required to cover costs*

Item	Quantity	Cost
Labor and power prior to harvest:		
Man labor	*Hours* 26.4	*Dollars* 4.62
Horse work	29.0	2.90
Total		7.52
Materials:	*Bushel*	
Summer cover crop, velvetbeans, at $2.50 per bushel	0.25	.62
Winter cover crop, oats, at $1 per bushel	1.00	[2] .33
Miscellaneous [3]		3.98
Total		4.93
Other costs:		
Taxes		1.30
Use of machinery [4]		1.28
Overhead [4]		1.87
Total		4.45
Total cost exclusive of interest		16.90
Interest at 6 per cent [4]		11.15
Total cost		28.05
Quantity of nuts at 31 cents per pound [5] required to cover costs, including harvesting:	*Pounds*	
Exclusive of interest	62	
Inclusive of interest	101	

[1] Trees set 60 by 60 feet, or 12 per acre, of which 2 per cent were missing, 80 per cent were in bearing, and 18 per cent were replants and not in bearing.
[2] Based on a winter cover crop of oats used on approximately one-third of the orchard acreage.
[3] Includes spray material, fertilizer, manure, and other materials.
[4] See p. 16 for methods of computing machinery, overhead, and interest charges.
[5] The 1928 Stat average farm price. Harvesting costs include picking, grading, and delivery to local shipping point, and are based on pecans sold to buyers by express.

Harvest costs in 1928 ranged from $1.50 to $4 per hundred pounds of nuts. The cost per pound of producing pecans will vary not only with the system of management, but also with the yields obtained. Of the orchards 15 to 19 years of age from which production records were obtained in 1928, over 50 per cent did not have yields sufficient to pay costs, including interest charges and harvesting costs. The other orchards had yields ranging up to 500 pounds an acre. This was in a year considerably above the average from a standpoint of yields. By enlarging the sample by the inclusion of other yield data obtained by the questionnaire method a comparable variation in yields is shown, with a large proportion of the orchards not producing yields sufficient to cover the yearly costs. On the basis of 12 trees to the acre, of which 80 per cent are in bearing, two-thirds of the orchards 15 to 19 years old did not have yields sufficient to pay costs, including interest and harvesting charges, based on the practices shown in Table 26.

Several factors in the Monticello district may operate, singly or in combination, in bringing about low yields. Failure to select a suitable site for the orchard with respect to soils and topography has often resulted in the planting of trees where it is difficult to secure economic yields. Inadequate financing of the enterprise at the outset may account for the neglect and resultant low yields caused by failure to provide for soil fertility and for the control of diseases and insect pests. Repeated top-working of trees to new varieties by some growers in an attempt to control scab accounts in part for the yield variations in that the entire orchard may not be in bearing at one time, with the degree of yielding capacity dependent on the length of time that the top-working has been done.

Individual orchards of well-chosen varieties have proved successful in those cases in which leguminous cover crops have been used, supplemented by commercial fertilizers and proper cultural practices, and diseases and insect pests have been controlled.

EASTERN DISTRICT

The orchards studied in the eastern district of Florida are in Alachua, Bradford, and Duvall Counties, the majority being in the first two counties. In this district it is a common practice to grow certain intercrops such as truck crops, corn, and occasionally cotton, in young orchards during the development period. For the first three or four years these crops are usually planted up to the trees, the orchard receiving the same cultivation as that given the intercrop. For the remainder of the development period, a free space on each side of the tree rows is cultivated independently. Cover crops are used in some of the orchards, but the practice is not common.

The tractor work is generally confined to disking the land. At rates prevailing in 1928, the total labor and power cost for the first 10 years to bring the orchard to bearing age is given in Table 27. The total cost, including interest compounded annually, plus land at $30, amounted to $168 an acre. (Table 28.)

TABLE 27.—*Florida, eastern district: Labor and power costs per acre of developing a pecan orchard during the first 10 years, according to a common method* [1] *and at cost rates prevailing in 1928*

Operation	Years operation is performed	Size of crew: Men	Size of crew: Horses	Size of crew: Tractor	Rate of work per day	Times done each year	Percentage charged to pecans	Charged to pecans: Man labor	Charged to pecans: Horse work	Charged to pecans: Tractor work	Cost
		Number	*Number*	*Number*	*Orchard acres*	*Number*	*Per cent*	*Hours*	*Hours*	*Hours*	*Dollars*
Plow	First to tenth	1	2		2	1	[2] 6-40	11.4	22.8		3.99
Harrow (disk)	do	1		1	15	1	[2] 6-40	1.9		1.9	2.66
Plant:											
Set stakes	First	2			20	1	100	1.0			.15
Dig holes	do	1			2	1	100	5.0			.75
Set trees	do	5	2		10	1	100	5.0	2.0		.95
Apply fertilizer around trees	First and second	2	2		25	1	100	1.6	1.6		.40
	Third	2	2		20	1	100	1.0	1.0		.25
	Fourth	2	2		16	1	100	1.2	1.2		.30
	Fifth and sixth	2	2		14	1	100	2.8	2.8		.70
	Seventh to tenth	2	2		10	1	100	8.0	8.0		2.00
Cultivate	First to fourth	1	1		4	3	[2] 6-12	2.7	2.7		.67
Cultivate tree rows	Fifth to seventh	1	2		20	3	100	4.5	9.0		1.58
	Eighth to tenth	1	2		15	3	100	6.0	12.0		2.10
Hoe around trees	First to third	1			12	2	100	5.1			.77
	Fourth	1			11	2	100	1.8			.27
	Fifth and sixth	1			10	1	100	2.0			.30
	Seventh	1			9	1	100	1.1			.16
	Eighth	1			8	1	100	1.2			.18
	Ninth	1			7	1	100	1.4			.21
	Tenth	1			6	1	100	1.7			.26
Supervision	First to tenth						100	18.7			5.61
Miscellaneous [3]	do						100	26.5	10.5		5.03
Total								111.6	73.6	1.9	29.29

[1] Trees set 50 by 50 feet or 17 to the acre. Interplanted crops grown up to and including the tree rows for the first 4 years. Tree-row spaces have a total width of about 12 feet for the following 3 years and 20 feet for the next 3 years. Tree-row space is cultivated independently from the fifth to tenth years; rest of space cropped in corn or other cultivated crop for harvest.

[2] Charges for land preparation prorated to pecans as follows: First year, 6 per cent; second year, 8 per cent; third year, 10 per cent; fourth year, 12 per cent; fifth to seventh year, 25 per cent; and eighth to tenth year, 40 per cent. Percentage charges to pecans for cultivations are the same as for land preparation for the first four years and 100 per cent from the fifth to tenth years.

[3] Includes applying manure, pruning, spraying, orchard sanitation, and replacing missing trees.

The practice of growing intercrops for harvest is usually discontinued when the young orchards come into commercial bearing. The majority of the bearing orchards are given clean cultivation. The practice of spraying or dusting and the use of cover crops are not common. Following the spring plowing, the bearing orchard is given clean cultivation with a disk harrow, the number of cultivations depending somewhat on weather conditions. The care of an acre of bearing orchard in eastern Florida usually involves slightly more than three days of man labor per acre and the necessary motive power for performing the field operations. Tractor-drawn disks are commonly used for cultivating. The labor and power cost in 1928, not including harvesting the crop, is shown in Table 29 and the total operating cost in Table 30. Harvesting costs in 1928 varied from $1.50 to $3.50 a hundred pounds of nuts.

TABLE 28.—*Florida, eastern district: Cost per acre of developing a pecan orchard for the first 10 years, by years, according to a common method and at cost rates prevailing in 1928*

Item	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	Ninth year	Tenth year
Fertilizer—pounds	34	51	68	102	119	136	153	170	170	170
Labor and power:										
Man labor—hours	19.2	8.4	8.5	8.2	10.1	9.0	9.5	12.4	13.6	12.7
Horse work—do	4.4	3.1	4.1	4.3	7.8	7.9	8.2	11.2	11.4	11.2
Tractor work—do	.1	.1	.1	.1	.2	.2	.2	.3	.3	.3
Labor and power:	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
Man labor [1]	3.36	1.47	1.48	1.44	1.77	1.57	1.66	2.17	2.38	2.22
Horse work at 10 cents per hour	.44	.31	.41	.43	.78	.79	.82	1.12	1.14	1.12
Tractor work at $1.25 per hour	.13	.13	.13	.13	.25	.25	.25	.38	.38	.38
Total	3.93	1.91	2.02	2.00	2.80	2.61	2.73	3.67	3.90	3.72
Materials:										
Trees at $1 each	17.00									
Fertilizer at $40 per ton	.68	1.02	1.36	2.04	2.38	2.72	3.06	3.40	3.40	3.40
Miscellaneous [2]	.33	.75	.77	.80	.97	1.06	.89	1.33	1.89	1.89
Total	18.01	1.77	2.13	2.84	3.35	3.78	3.95	4.73	5.29	5.29
Other costs:										
Taxes [3]	.08	.10	.12	.15	.31	.31	.31	.50	.50	.50
Use of machinery [4]	.16	.13	.17	.19	.32	.32	.33	.46	.47	.46
Overhead [4]	3.29	.55	.62	.73	.92	.96	1.00	1.26	1.38	1.35
Total	3.53	.78	.91	1.07	1.55	1.59	1.64	2.22	2.35	2.31
Total cost, exclusive of interest	25.47	4.46	5.06	5.91	7.70	7.98	8.32	10.62	11.54	11.32
Interest at 6 per cent [3 4]	.16	1.73	2.15	2.63	3.42	4.09	4.81	5.92	6.92	8.02
Total cost	25.63	6.19	7.21	8.54	11.12	12.07	13.13	16.54	18.46	19.34
Cost of development at end of each year [5]	55.63	61.82	69.03	77.57	88.69	100.76	113.89	130.43	148.89	168.23

[1] Ordinary labor charged at 15 cents per hour, supervision at 30 cents per hour.
[2] Includes replants, spray material, and manure.
[3] Charges for taxes and interest prorated to pecan trees as follows: First year, 6 per cent; second year, 8 per cent; third year, 10 per cent; fourth year, 12 per cent; fifth to seventh years, 25 per cent; eighth to tenth years, 40 per cent.
[4] See p. 16 for method of computing machinery, overhead, and interest charges.
[5] Total cost, including interest plus initial value of land at $30 an acre.

TABLE 29.—*Florida, eastern district: Annual labor and power cost per acre of operating pecan orchards 15 to 19 years old [1] up to harvest time, according to a common method, and at cost rates prevailing in 1928 [2]*

Operation	Size of crew			Rate of work per day	Times done	Man labor	Horse work	Tractor work	Cost
	Men	Horses	Tractor						
	Number	*Number*	*Number*	*Orchard acres*	*Number*	*Hours*	*Hours*	*Hours*	*Dollars*
Prune	1			5	1	2.0			0.30
Remove pruned wood	1	2		12	1	.8	1.6		.28
Orchard sanitation						2.4	1.0		.46
Plow	1	1		1	1	10.0	10.0		2.50
Apply fertilizer around trees	2	2		8	1	2.5	2.5		.62
Cultivate (disk harrow)	1		1	15	2	1.3		1.3	1.82
Supervision						5.2			1.56
Miscellaneous [3]						7.0	4.1	.3	1.84
Total						31.2	19.2	1.6	9.38

[1] Trees set 50 by 50 feet, or 17 to the acre, of which 3 per cent were missing, 95 per cent were in bearing, and 2 per cent were not in bearing—mainly replants.
[2] Ordinary labor at 15 cent an hour, supervision at 30 cents, horse work at 10 cents, and use of tractor at $1.25.
[3] Includes hoeing, applying manure, spraying, sowing cover crop, and miscellaneous operations.

TABLE 30.—*Florida, eastern district: Annual cost per acre of operating pecan orchards 15 to 19 years old* [1] *according to a common method and at cost rates prevailing in 1928, and yield required to cover costs*

Item	Quantity	Cost
Labor and power prior to harvest:	*Hours*	*Dollars*
Man labor	31.2	5.46
Horse work	19.2	1.92
Tractor work	1.6	2.00
Total		9.38
Materials:	*Pounds*	
Fertilizer at $40 per ton	330	6.60
Miscellaneous [2]		2.68
Total		9.28
Other costs:		
Taxes		1.25
Use of machinery, not including tractor [3]		1.24
Overhead [3]		2.80
Total		5.29
Total cost exclusive of interest		23.95
Interest at 6 per cent [3]		10.55
Total cost		34.50
Quantity of nuts at 31 cents per pound [4] required to cover cost including harvest:		
Exclusive of interest	86	
Inclusive of interest	123	

[1] Trees set 50 by 50 feet, or 17 to the acre, of which 3 per cent were missing, 95 per cent were in bearing, and 2 per cent were not in bearing—mainly replants.
[2] Includes spray material, cover-crop seed, manure, and other materials.
[3] See p. 16 for method of computing machinery, overhead, and interest charges.
[4] The 1928 State average farm price. Harvesting costs include picking, grading, and delivery to local shipping point and are based on pecans sold to buyers by freight.

The range of yields reported in the district reveals that many orchards did not have a yield sufficiently high to cover costs, while others showed a sizable margin of profit. A few of the orchards reported practically no yields, others had varying yields, the highest running up to 594 pounds an acre.

Although variations in yields between orchards are affected largely by differences in ages of plantings, a wide range in yields also exists between orchards classed in the same age group. Of the group of orchards 15 to 19 years old from which production records were obtained, 33⅓ per cent did not have yields sufficient to pay costs computed on the basis of the common method of operating orchards in the district. (Table 29.) The care given some of the orchards would not entail a per-acre cost as high as that shown in Table 30, but the returns in most cases were correspondingly lower.

The principal factors affecting pecan yields in this district are similar to those outlined in the discussion of conditions in the Monticello district. An especially important factor in this district is the selection of a suitable site for the orchard with respect to fertility of soil. This is especially important in sections where intercrops are to be used. Failure to recognize this fundamental principle has resulted in many cases in placing orchards in which there is apparently small prospect of ever obtaining profitable yields.

ALABAMA

MOBILE DISTRICT

The orchards studied in the Mobile district are all in Mobile County. Pecan and Satsuma orange trees are commonly planted in the same

orchard at the rate of 8 orange trees to 1 pecan tree, making 12 pecan and 96 Satsuma trees to the acre. Since the general system of orchard development and management is concerned with a combination pecan-orange orchard, any computation of the costs chargeable to pecans must apportion those costs common to both. Certain operations, such as planting, pruning, and fertilizing, are done on one or the other of the two kinds of trees and are therefore chargeable directly to the trees for which performed. Other operations, such as plowing, cultivating, and seeding cover crops, are chargeable to both and have been apportioned accordingly.

These estimates of cost prorations were based on the relative orchard area occupied by each kind of tree. As the pecan trees increased in size and occupied relatively more of the orchard space, they were charged with a greater proportion of those cost items common to both. The portion of the joint expenses chargeable to pecans for each year of the development period is shown in the footnotes to Tables 31 and 32.

TABLE 31.—*Alabama, Mobile district: Labor and power costs per acre of developing a pecan orchard during the first 10 years, with Satsuma oranges set as fillers,* [1] *and at cost rates prevailing in 1928*

Operation	Years operation is performed	Size of crew			Rate of work per day	Times done each year	Percentage charged to pecans	Charged to pecans			Cost
		Men	Horses	Tractors				Man labor	Horse work	Tractor work	
		Number	*Number*	*Number*	*Orchard acres*	*Number*	*Per cent*	*Hours*	*Hours*	*Hours*	*Dollars*
Plow	First to tenth	1		1	4	1	[2] 10–20	2.9		2.9	4.28
Harrow (disk)	First	1		1	15	1	10	.1		.1	.15
Plant:											
Set stakes	do	3			25	1	100	1.2			.27
Dig holes	do	2			7	1	100	2.9			.65
Set trees	do	5	2		14	1	100	3.6	1.4		1.02
Apply fertilizer around trees.	do	3	2		50	1	100	.6	.4		.19
	Second	3	2		40	1	100	.8	.5		.25
	Third	3	2		34	1	100	.9	.6		.29
	Fourth	3	2		28	1	100	1.1	.7		.35
	Fifth	3	2		24	1	100	1.2	.8		.39
	Sixth	3	2		22	1	100	1.4	.9		.45
	Seventh	3	2		20	1	100	1.5	1.0		.49
	Eighth	3	2		18	1	100	1.7	1.1		.55
	Ninth and tenth	3	2		16	1	100	3.8	2.4		1.22
Cultivate (disk harrow).	First to tenth	1		1	15	7	[2] 10–20	6.0		6.0	8.85
Hoe around trees	First to fourth	1			15	4	100	10.8			2.43
	Fifth and sixth	1			12	1	100	1.6			.36
	Seventh and eighth.	1			10	1	100	2.0			.45
	Ninth and tenth	1			8	1	100	2.4			.54
Seed cover crop	Second to tenth	1	2		10	1	[2] 10–20	1.2	2.4		.63
Prune	do						100	12.6			2.83
Remove pruned wood.	Sixth to tenth						100	3.3	3.3		1.24
Supervision	First to tenth						100	15.1			6.80
Miscellaneous [3]	do						100	11.7			2.63
Total								90.4	15.5	9.0	37.31

[1] Pecan trees set 60 by 60 feet, and Satsumas as fillers—about 12 pecan trees and 96 Satsuma trees per acre. No interplanted crop grown for harvest during development period.

[2] Charges for land preparation, cultivation, and seeding of cover crop charged to pecans as follows: First five years, 10 per cent; sixth year, 11 per cent; seventh year, 13 per cent; eighth year, 15 per cent; ninth year, 17 per cent; and tenth year, 20 per cent.

[3] Includes treatment for borers, spraying, applying manure, and replacing missing trees.

TABLE 32.—*Alabama, Mobile district: Cost per acre of developing a pecan orchard for the first 10 years, by years, according to a common method and at cost rates prevailing in 1928*

Item	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	Ninth year	Tenth year
Fertilizer—pounds	24	48	72	96	120	144	168	192	216	240
Labor and power:										
Man labor—hours	14.3	9.1	8.3	7.3	6.0	7.7	8.5	9.0	10.0	10.2
Horse work—do	1.8	.7	.8	.9	1.0	1.7	1.8	2.2	2.3	2.3
Tractor work—do	.8	.7	.7	.7	.7	.8	.9	1.1	1.2	1.4
Labor and power:	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
Man labor [1]	3.76	2.39	2.18	1.91	1.58	2.02	2.23	2.36	2.63	2.68
Horse work at 15 cents per hour	.27	.10	.12	.14	.15	.25	.27	.33	.34	.34
Tractor work at $1.25 per hour	1.00	.88	.88	.88	.88	1.00	1.12	1.37	1.50	1.75
Total	5.03	3.37	3.18	2.93	2.61	3.27	3.62	4.06	4.47	4.77
Materials:										
Trees at 75 cents each	9.00									
Fertilizer at $37.50 per ton	.45	.90	1.35	1.80	2.25	2.70	3.15	3.60	4.05	4.50
Cover crop seed (vetch) at 12 cents per pound		.24	.24	.24	.24	.26	.31	.36	.41	.48
Miscellaneous [2]	.28	.54	.28	.15	.08	.08	.10	.08	.08	.08
Total	9.73	1.68	1.87	2.19	2.57	3.04	3.56	4.04	4.54	5.06
Other costs:										
Taxes [3]	.04	.04	.04	.04	.04	.04	.05	.06	.07	.08
Use of machinery [4]	.07	.02	.03	.03	.04	.06	.07	.08	.09	.09
Overhead [4]	2.21	.76	.76	.77	.78	.95	1.08	1.22	1.35	1.47
Total	2.32	.82	.83	.84	.86	1.05	1.20	1.36	1.51	1.64
Total cost, exclusive of interest	17.08	5.87	5.88	5.96	6.04	7.36	8.38	9.46	10.52	11.47
Interest at 6 per cent [3 4]	.20	1.22	1.65	2.10	2.59	3.13	3.80	4.57	5.45	6.46
Total cost	17.28	7.09	7.53	8.06	8.63	10.49	12.18	14.03	15.97	17.93
Cumulative cost [5]	17.28	24.37	31.90	39.96	48.59	59.08	71.26	85.25	101.26	119.19

[1] Ordinary labor at 22½ cents per hour, supervision at 45 cents per hour.
[2] Includes trees for replanting, spraying, manuring, and other items.
[3] Charges for taxes and interest prorated to pecan trees as follows: First 5 years, 10 per cent; sixth year, 11 per cent; seventh year, 13 per cent; eighth year, 15 per cent; ninth year, 17 per cent; and tenth year, 20 per cent.
[4] See p. 16 for method of computing machinery, overhead, and interest charges.
[5] Includes interest on the value of the proportion of an acre of land occupied by pecan trees. The initial value of the land, $30 per acre, is not included.

During the development period a winter cover crop of vetch is turned under in the spring and the pecan trees are fertilized independently of the orange trees. The entire orchard is then given clean cultivation during the growing season. Neither spraying nor dusting of pecan trees is practiced to any extent. Comparatively large orchards with rather level surface and the practice of clean cultivation are factors favoring the use of tractor-drawn implements for such operations as plowing, disking, and cultivating. An acre of land of the character set to pecan and orange trees is valued generally at about $30 an acre.

The combination of orange and pecan trees is maintained in bearing orchards, and the same general system of orchard practice is followed as for young orchards. In orchards 15 to 19 years of age crowding has not yet been serious enough to necessitate any change in the original arrangement. The proportionate share of the joint expenses of operation chargeable to pecans is shown in Tables 33 and 34. It is probable that with increasing age and size of the trees it may become necessary to thin the orchard to prevent detrimental overcrowding.

Present plans call for the removal of some of the orange trees when this becomes necessary.

Tractors are the usual source of motive power for plowing and cultivating. For the pecan trees, the cost of labor and power, not including harvesting the crop, is shown in Table 33. The total 1928 operating cost chargeable to pecans, excluding harvesting costs, is given in Table 34. Harvest costs in 1928 varied from $1.50 to $3 per hundred pounds of nuts, depending largely on the yield obtained.

TABLE 33.—*Alabama, Mobile district: Annual labor and power cost per acre of operating pecan orchards 15 to 19 years old* [1] *up to harvest time, according to a common method, and at cost rates prevailing in 1928* [2]

Operation	Size of crew			Rate of work per day	Times done	Percentage charged to pecans	Charged to pecans			
	Men	Horses	Tractors				Man labor	Horse work	Tractor work	Cost
	Number	*Number*	*Number*	*Orchard acres*	*Number*	*Per cent*	*Hours*	*Hours*	*Hours*	*Dollars*
Prune	1			1.25	1	100	8.0			1.80
Remove pruned wood	2	2		10	1	100	2.0	2.0		.75
Plow	1		1	4	1	35	.9		0.9	1.33
Apply fertilizer around trees	5	2		25	2	100	4.0	1.6		1.14
Cultivate (disk harrow)	1		1	15	6	35	1.4		1.4	2.06
Seed cover crop	1	2		10	1	35	.4	.8		.21
Supervision						100	4.3			1.94
Miscellaneous [3]						100	5.0	4.1		1.74
Total							26.0	8.5	2.3	10.97

[1] Based on Satsuma oranges set as fillers in the pecan orchard. One acre of orchard when planted with pecan trees, set 60 by 60 feet, and Satsumas as fillers, contains about 12 pecan trees and 96 Satsuma trees. Ninety per cent of the pecan trees were in bearing, 5 per cent missing, and 5 per cent not in bearing—mainly replants.

[2] Ordinary labor at 22½ cents per hour, supervision at 45 cents, horse work at 15 cents, and use of tractor at $1.25.

[3] Includes orchard sanitation, spraying, mowing weeds, and other operations.

Yields in the Mobile district were exceptionally favorable in 1928, compared with other seasons. (Table 8.) Of the orchards from which production records for 1928 were secured by personal visits, yields from orchards 15 to 19 years of age averaged 323 pounds an acre. All orchards studied showed yields that were more than sufficient to cover the cost of production computed on the basis of the common method of operating pecan orchards in the district. (Table 34.) Production ranged from 277 pounds an acre for the orchard reporting the lowest to 585 pounds an acre for the orchard reporting the highest yield.

The orchards studied yielded practically nothing during the two years preceding 1928. These two crop failures were attributed by orchardists largely to a severe storm in the latter part of 1926 which damaged the trees considerably. In 1925 when relatively normal conditions prevailed compared with other years, yields averaged 180 pounds an acre. Production ranged from 69 pounds an acre for the orchard having the lowest yield to 425 pounds an acre for the orchard having the highest. The effect of conditions during the preceding years on the yields obtained in the area in 1928 is problematical. These conditions are mentioned here, however, to give a better perspective than is afforded when results secured in any one year are viewed. The yields obtained from some individual orchards in the Mobile district for a period of years are shown in Table 14.

TABLE 34.—*Alabama, Mobile district: Annual cost per acre of operating pecan orchards 15 to 19 years old* [1] *according to a common method and at cost rates prevailing in 1928, and yield required to cover costs*

Item	Quantity	Cost
Labor and power prior to harvest:		
Man labor	*Hours* 26.0	*Dollars* 6.82
Horse work	8.5	1.28
Tractor work	2.3	2.87
Total		10.97
Materials:		
Fertilizer at $37.50 per ton	*Pounds* 570	10.69
Winter cover crop, vetch at 12 cents per pound	20	[2] .84
Miscellaneous [3]		.60
Total		12.13
Other costs:		
Taxes [2]		.14
Use of machinery, not including tractor [4]		.90
Overhead [4]		3.46
Total		4.50
Total cost, exclusive of interest		27.60
Interest at 6 per cent [2 4]		8.14
Total cost		35.74
Quantity of nuts at 30 cents per pound [5] required to cover cost including harvest:		
Exclusive of interest	102	
Inclusive of interest	132	

[1] Trees set 60 by 60 feet, with Satsuma oranges as fillers, or 12 pecan trees and 96 Satsuma trees to the acre. Five per cent of the pecan trees were missing, 90 per cent were bearing, and 5 per cent were not in bearing—mainly replants.

[2] 35 per cent of the cost of cover-crop seed and taxes and interest was charged to pecans.

[3] Includes spray, paint, and other materials.

[4] See p. 16 for method of computing machinery, overhead, and interest charges.

[5] The 1928 State average farm price. Harvesting costs include picking, grading, and delivery to local shipping point and are based on pecans sold to local dealers.

SELMA DISTRICT

The orchards studied in the Selma district of Alabama are in Dallas and Lowndes Counties, the majority being in Dallas County. With few exceptions, the development of a pecan orchard in this district is incidental to the production of field crops for harvest. Cotton and other field crops for harvest are interplanted up to the trees during the entire development period. Cotton is usually interplanted for four successive years, alternating with corn, potatoes, or some other crop for harvest the fifth year. Spraying or dusting is not commonly done in young orchards. The use of tractor-drawn implements is not common in the development of young orchards largely because of the interplanting of row crops, mostly cotton, grown mainly by share labor.

The total labor and power cost for the first 10 years is shown in Table 35. At the end of the tenth year the total cost, including interest compounded annually, plus the value of the land at $25, amounted to about $104 an acre. (Table 36.)

TABLE 35.—*Alabama, Selma district: Labor and power costs per acre of developing a pecan orchard during the first 10 years, according to a common method* [1] *and at cost rates prevailing in 1928*

Operation	Years operation is performed	Size of crew		Rate of work per day	Times done each year	Percentage charged to pecans	Charged to pecans		Cost
		Men	Horses				Man labor	Horse work	
		Number	*Number*	*Orchard acres*	*Number*	*Per cent*	*Hours*	*Hours*	*Dollars*
Plow	First	1	2	1.5	2	5	0.7	1.4	0.21
	Second to tenth	1	2	1.5	1	[2] 5–22	7.9	15.8	2.37
Harrow	First	1	4	10	1	5	.1	.4	.05
Plant:									
Set stakes	do	3		25		100	1.2		.12
Dig holes	do	1		3.5		100	2.9		.29
Set trees	do	3	2	12		100	2.5	1.7	.42
Harrow	First to tenth	1	1	7	1	[2] 5–22	1.8	1.8	.36
Stake trees	First	2	2	10	1	100	2.0	2.0	.40
Cultivate	First to tenth	1	1	3.5	([3])	[2] 5–22	18.2	18.2	3.64
Hoe around trees	First and second	1		25	3	100	2.4		.24
	Third and fourth	1		20	3	100	3.0		.30
	Fifth	1		18	3	100	1.7		.17
	Sixth to eighth	1		15	3	100	6.0		.60
	Ninth and tenth	1		12	3	100	5.0		.50
Prune	Second to tenth					100	5.0		.50
Remove pruned wood	Seventh to tenth					100	1.6	3.2	.48
Supervision	First to tenth					100	16.4		3.28
Miscellaneous [4]	do					100	20.5	8.5	2.90
Total							98.9	53.0	16.83

[1] Trees set 60 feet by 60 feet, or 12 to the acre. Cotton, usually planted for four successive years and alternated with corn or some other cultivated crop for harvest the fifth year, interplanted up to and including the tree rows during the entire development period.

[2] Charges for land preparation and cultivation prorated to pecans as follows: First year, 5 per cent; second year, 5 per cent; third year, 7 per cent; fourth year, 9 per cent; fifth year, 11 per cent; sixth year, 13 per cent; seventh year, 15 per cent; eighth year, 17 per cent; ninth year, 19 per cent; tenth year, 22 per cent.

[3] Pecan trees cultivated the same as the interplanted crop for harvest on the basis of six cultivations for cotton and three for corn and other cultivated crops for harvest.

[4] Includes the application of commercial fertilizer and manure, spraying, and replacing missing trees.

Crops for harvest are usually not grown in bearing orchards. In the fall, a winter cover crop, usually vetch, is sowed by hand at the rate of 20 pounds to the acre. Harrowing in the seed with a disk harrow also serves to clean the ground for harvest. In the spring commercial fertilizer is applied on top of the cover crop around the trees, and both crop and fertilizer are turned under with a double-cut disk harrow. Clean cultivation is practiced during the summer. Little spraying or dusting is done in orchards of bearing age. The care of an acre of bearing orchard in the Selma district usually requires about 13 hours of man labor plus the necessary motive power to perform the field operations. Tillage and the work in connection with a winter cover crop are usually done with tractor-drawn implements. The power requirements per acre amounted to slightly less than 4 tractor hours and about 4.5 horse hours. (Table 37.) The total 1928 operating cost is shown in Table 38. Harvesting costs in 1928 varied from $1.50 to $3.50 per hundred pounds of nuts.

TABLE 36.—*Alabama, Selma district: Cost per acre of developing a pecan orchard for the first 10 years, by years, according to a common method and at cost rates prevailing in 1928*

Item	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	Ninth year	Tenth year
Labor and power:										
Man labor, hours	15.0	5.0	6.2	7.9	7.8	9.6	11.3	11.2	12.5	12.4
Horse labor, do	7.0	2.0	2.9	3.5	3.3	5.2	6.6	6.9	8.1	7.5
Labor and power:	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
Man labor [1]	1.74	0.58	0.72	0.92	0.91	1.12	1.32	1.31	1.46	1.45
Horse work at 10 cents per hour	.70	.20	.29	.35	.33	.52	.66	.69	.81	.75
Total	2.44	.78	1.01	1.27	1.24	1.64	1.98	2.00	2.27	2.20
Materials:										
Trees at $1 each	12.00									
Stakes for young trees at 6 cents each	1.44									
Miscellaneous [2]	.80	1.40	.75	1.50	1.20	1.08	1.80	1.80	2.00	1.95
Total	14.24	1.40	.75	1.50	1.20	1.08	1.80	1.80	2.00	1.95
Other costs:										
Taxes [3]	.04	.04	.05	.07	.08	.10	.11	.13	.14	.16
Use of machinery [4]	.26	.08	.11	.13	.12	.20	.25	.26	.30	.28
Overhead [4]	2.50	.33	.26	.42	.37	.41	.57	.57	.64	.62
Total	2.80	.45	.42	.62	.57	.71	.93	.96	1.08	1.06
Total cost, exclusive of interest	19.48	2.63	2.18	3.39	3.01	3.43	4.71	4.76	5.35	5.21
Interest at 6 per cent [3 4]	.15	1.28	1.55	1.81	2.15	2.51	2.91	3.40	3.94	4.53
Total cost	19.63	3.91	3.73	5.20	5.16	5.94	7.62	8.16	9.29	9.74
Cost of development at end of each year [5]	44.63	48.54	52.27	57.47	62.63	68.57	76.19	84.35	93.64	103.38

[1] Ordinary labor charged at 10 cents per hour, supervision at 20 cents per hour.
[2] Includes fertilizer, manure, replants, spray material, and other materials.
[3] Charges for taxes and interest prorated to pecan trees as follows: First year, 5 per cent; second year, 5 per cent; third year, 7 per cent; fourth year, 9 per cent; fifth year, 11 per cent; sixth year, 13 per cent; seventh year, 15 per cent; eighth year, 17 per cent; ninth year, 19 per cent; tenth year, 22 per cent.
[4] See p. 16 for method of computing machinery, overhead, and interest charges.
[5] Total cost including interest plus initial value of land, at $25 an acre.

TABLE 37.—*Alabama, Selma district: Annual labor and power cost per acre of operating pecan orchards 15 to 19 years old [1] up to harvest time, according to a common method, and at cost rates prevailing in 1928 [2]*

Operation	Size of crew			Rate of work per day	Times done	Man labor	Horse work	Tractor work	Cost
	Men	Horses	Tractors						
	Number	*Number*	*Number*	*Orchard acres*	*Number*	*Hours*	*Hours*	*Hours*	*Dollars*
Prune	1			10	1	1.0			0.10
Remove pruned wood	2	2		25	1	.8	0.8		.16
Apply fertilizer around trees	1	2		20	1	2.0	1.0		.30
Disk under winter cover crop	1		1	15	2	1.3		1.3	1.76
Cultivate (disk harrow)	1		1	25	6	2.4		2.4	3.24
Orchard sanitation	2	2		30	1	.7	.7		.14
Sow winter cover crop	1			20	1	.5			.05
Disk in cover crop seed	1		1	15	1	.7	.7		.14
Supervision						2.1			.42
Miscellaneous [3]						1.2	1.2		.24
Total						12.7	4.4	3.7	6.55

[1] Trees set 60 by 60 feet, or 12 to the acre, of which 8 per cent were missing, 85 per cent were in bearing, and 7 per cent were not in bearing—mainly replants.
[2] Ordinary labor at 10 cents an hour, supervision at 20 cents, horse work at 10 cents, and use of tractor at $1.25.
[3] Includes manuring, hoeing, spraying, and miscellaneous operations.

TABLE 38.—*Alabama, Selma district: Annual cost per acre of operating pecan orchards 15 to 19 years old* [1] *according to a common method and at cost rates prevailing in 1928, and yield required to cover costs*

Item	Quantity	Cost
Labor and power prior to harvest:	*Hours*	*Dollars*
Man labor	12.7	1.48
Horse work	4.4	.44
Tractor work	3.7	4.63
Total		6.55
Materials:	*Pounds*	
Fertilizer, basic slag at $10 per ton	275	1.38
Winter cover crop, vetch at 12 cents per pound	20	2.40
Miscellaneous [2]		2.27
Total		6.05
Other costs:		
Taxes		.75
Use of machinery, not including tractor [3]		.30
Overhead [3]		1.89
Total		2.94
Total cost, exclusive of interest		15.54
Interest at 6 per cent [3]		6.48
Total cost		22.02
Quantity of nuts at 30 cents per pound [4] required to cover cost including harvesting:		
Exclusive of interest	59	
Inclusive of interest	82	

[1] Trees set 60 by 60 feet, or 12 to the acre, of which 8 per cent were missing, 85 per cent were in bearing, and 7 per cent were not in bearing—mainly replants.
[2] Includes spray material, manure, and other materials.
[3] See p. 16 for method of computing machinery, overhead, and interest charges.
[4] The 1928 average State farm price. Harvesting costs include picking, grading, and delivery to local shipping point and are based on pecans sold through a cooperative association.

On the orchards of 15 to 19 years of age in this district from which production records were obtained by means of personal visits, yields in 1928 ranged from 16 pounds an acre for the orchard having the lowest yield to 375 pounds an acre for the orchard having the highest. Approximately 43 per cent of the orchards did not have yields sufficient to cover the costs of operation, including interest charges and harvesting costs, computed on the basis of the most common practices followed in the district. This was in a year when yields in Alabama were relatively high compared with those of other seasons. (Table 8.)

Consideration of other production data for Alabama reveals a somewhat comparable variation in yields obtained from pecan orchards over the State. The relative degree of success achieved by orchardists, from a yield standpoint, may be noted from the distribution of pecan orchards on the basis of the average yield per tree in 1928. The 86 orchards of improved varieties 15 to 19 years of age for which production data are shown consisted mainly of Stuart, Schley, Success, and Frotscher varieties, with smaller numbers of trees of other varieties.

Yield per tree, in pounds	Number of orchards	Yield per tree, in pounds	Number of orchards
0–4.9	17	40–44.9	4
5–9.9	16	45–49.9	0
10–14.9	14	50–54.9	0
15–19.9	12	55–59.9	1
20–24.9	8	60–64.9	1
25–29.9	5	65–69.9	1
30–34.9	2	70 and over	5
35–39.9	0		

An active interest in the production of pecans to supplement the income from cotton has led to a considerable expansion of plantings in the Selma district. As in most of the other districts included in this study, however, there has been considerable misapprehension in the Selma district as to the amount of care and attention required by pecan trees. As a result, many of the young orchards have been neglected to some extent, with a consequent development of some orchards that are severely handicapped in their ability to produce economic yields.

Successful orchardists have recognized the necessity of planting the trees only on fertile land and maintaining that fertility to meet the requirements of the growing trees and the intercrops. In connection with this, other factors, which must be considered as contributory to ultimate success and which are applicable to pecan orchards in all areas, have been pointed out in the discussions of pecan production in other districts. The most important factors in this district are the choice of suitable varieties adapted to the area; planting the trees at distances that will permit a good development of the orchard, and following the necessary orchard practices of cultivation, pruning, and control measures for insects and diseases, with a view to obtaining the maximum production compatible with sound economy.

EUFAULA DISTRICT

The orchards studied in the Eufaula district are all in Barbour County. In this district the majority of the young orchards are interplanted with field crops for harvest during the entire development period. Crops are planted up to the trees without allowing any free space for the independent cultivation of the trees. Cotton is usually alternated with corn or some other crop for harvest. During the first few years, stakes are used around the trees to prevent injury during cultivation. Although crops are planted up to the trees, because of shading very little or no production is expected from the area immediately around the trees. This shaded area increases in size with the age and size of the trees.

The total labor and power cost for the first 10 years is shown in Table 39. In 1928 pecan orchard land was valued at about $25 an acre. The cost of development for 10 years, plus the value of the land on which the trees were set, is shown in Table 40.

TABLE 39.—*Alabama, Eufaula district: Labor and power costs per acre of developing a pecan orchard during the first 10 years, according to a common method* [1] *and at cost rates prevailing in 1928*

Operation	Years operation is performed	Size of crew		Rate of work per day	Times done each year	Percentage charged to pecans	Charged to pecans		Cost
		Men	Horses				Man labor	Horse work	
		Number	*Number*	*Orchard acres*	*Number*	*Per cent*	*Hours*	*Hours*	*Dollars*
Plow	First to tenth	1	2	1.5	1	[2] 5–22	8.2	16.4	3.08
Harrow	do	1	1	8	1	[2] 5–22	1.6	1.6	.40
Plant:									
Set stakes	First	3		25	1	100	1.2		.15
Dig holes	do	1		3	1	100	3.3		.41
Set trees	do	3	2	10	1	100	3.0	2.0	.62
Stake trees	do	2	2	10	1	100	2.0	2.0	.50
Apply fertilizer around trees	First	3	2	45	1	100	.7	.4	.14
	Second	3	2	40	1	100	.8	.5	.16
	Third and fourth	3	2	35	1	100	1.8	1.2	.38
	Fifth and sixth	3	2	30	1	100	2.0	1.4	.42
	Seventh	3	2	25	1	100	1.2	.8	.25
	Eighth and ninth	3	2	20	1	100	3.0	2.0	.62
	Tenth	3	2	18	1	100	1.7	1.1	.35
Cultivate	First to tenth	1	1	3	[3]	[2] 5–22	18.0	18.0	4.50
Hoe around trees	First	1		25	2	100	.8		.10
	Second	1		20	2	100	1.0		.12
	Third and fourth	1		18	2	100	2.2		.28
	Fifth	1		16	2	100	1.2		.15
	Sixth and seventh	1		15	2	100	2.7		.34
	Eighth	1		14	2	100	1.4		.18
	Ninth and tenth	1		12	2	100	3.3		.41
Prune	Second to tenth					100	4.9		.61
Remove pruned wood	Fifth to tenth					100	2.1	4.2	.79
Supervision	First to tenth					100	16.7		4.18
Miscellaneous [4]	do					100	15.3	17.0	4.04
Total							100.1	68.6	23.18

[1] Pecan trees set 60 by 60 feet or 12 to the acre. Cotton usually rotated with corn or some other cultivated crop for harvest, interplanted up to and including the tree rows during the entire development period.

[2] Charges for land preparation and cultivation prorated to pecans as follows: First year, 5 per cent; second year, 5 per cent; third year, 7 per cent; fourth year, 9 per cent; fifth year, 11 per cent; sixth year, 13 per cent; seventh year, 15 per cent; eighth year, 17 per cent; ninth year, 19 per cent; tenth year, 22 per cent.

[3] Pecan trees cultivated the same as the interplanted crop for harvest on the basis of six cultivations for cotton and three for corn and other cultivated crops for harvest.

[4] Includes manuring, spraying, seeding cover crop, orchard sanitation, and replacing missing trees.

After the orchard has come into commercial bearing the interplanting of field crops for harvest is usually discontinued. A winter cover crop, usually vetch, is sowed broadcast by hand in the fall at the rate of 18 pounds to the acre and is worked in with a disk harrow. The following spring, commercial fertilizer is scattered over the surface of the cover crop around the trees and is turned under with a disk plow. During the growing season about six cultivations are given the orchard with a disk harrow.

The care of an acre of bearing orchard in the Eufaula district usually requires slightly less than 1.5 days of man labor and the necessary motive power for performing the field operations. The operations commonly performed with tractor-drawn implements are plowing, cultivating, and drilling in winter cover-crop seed. The labor and power cost, not including harvesting the crop, is shown in Table 41. The total 1928 operating cost is shown in Table 42. Harvesting costs in 1928 ranged from $1.50 to $3 per hundred pounds of nuts.

TABLE 40.—*Alabama, Eufaula district: Cost per acre of developing a pecan orchard for the first 10 years, by years, according to a common method and at cost rates prevailing in 1928*

Item	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	Ninth year	Tenth year
Fertilizer—pounds	24	36	60	60	84	84	96	120	120	144
Labor and power:										
Man labor—hours	15.2	4.6	6.1	5.8	14.6	8.5	10.7	9.8	13.0	11.8
Horse work—do	6.3	2.5	3.9	3.6	11.2	6.5	8.3	7.4	9.9	9.0
Labor and power:	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
Man labor [1]	2.21	0.68	0.89	0.85	2.12	1.24	1.56	1.42	1.90	1.73
Horse work at 12½ cents per hour	.79	.31	.49	.45	1.40	.81	1.04	.93	1.24	1.12
Total	3.00	.99	1.38	1.30	3.52	2.05	2.60	2.35	3.14	2.85
Materials:										
Trees at $1 each	12.00									
Stakes for young trees at 6 cents each	1.44									
Fertilizer at $28 per ton	.34	.50	.84	.84	1.18	1.18	1.34	1.68	1.68	2.02
Miscellaneous [2]	.95	.91	.48	.41	1.97	1.14	.88	.84	.82	.80
Total	14.73	1.41	1.32	1.25	3.15	2.32	2.22	2.52	2.50	2.82
Other costs:										
Taxes [3]	.04	.04	.05	.07	.08	.10	.11	.13	.14	.16
Use of machinery [4]	.24	.09	.15	.14	.42	.24	.31	.28	.37	.34
Overhead [4]	2.66	.36	.40	.38	1.00	.66	.72	.73	.85	.85
Total	2.94	.49	.60	.59	1.50	1.00	1.14	1.14	1.36	1.35
Total cost, exclusive of interest	20.67	2.89	3.30	3.14	8.17	5.37	5.96	6.01	7.00	7.02
Interest at 6 per cent [3 4]	.15	1.35	1.65	1.98	2.40	3.01	3.56	4.16	4.82	5.57
Total cost	20.82	4.24	4.95	5.12	10.57	8.38	9.52	10.17	11.82	12.59
Cost of development at end of each year [5]	45.82	50.06	55.01	60.13	70.70	79.08	88.60	98.77	110.59	123.18

[1] Ordinary labor charged at 12½ cents per hour, supervision at 25 cents per hour.
[2] Includes manure, spray material, cover-crop seed, replants, and other materials.
[3] Charges for taxes and interest prorated to pecan trees as follows: First year, 5 per cent; second year, 5 per cent; third year, 7 per cent; fourth year, 9 per cent; fifth year, 11 per cent; sixth year, 13 per cent; seventh year, 15 per cent; eighth year, 17 per cent; ninth year, 19 per cent; tenth year, 22 per cent.
[4] See p. 16 for method of computing machinery, overhead, and interest charges.
[5] Total cost including interest plus initial value of land, at $25 per acre.

TABLE 41.—*Alabama, Eufaula district: Annual labor and power cost per acre of operating pecan orchards 15 to 19 years old [1] up to harvest time, according to a common method, and at cost rates prevailing in 1928 [2]*

Operation	Size of crew			Rate of work per day	Times done	Man labor	Horse work	Tractor work	Cost
	Men	Horses	Tractors						
	Number	*Number*	*Number*	*Orchard acres*	*Number*	*Hours*	*Hours*	*Hours*	*Dollars*
Prune	1			10	1	1.0			0.12
Remove pruned wood	2	2		25	1	.8	0.8		.20
Apply fertilizer around trees	2	2		10	1	2.0	2.0		.50
Plow cover crop under	1		1	5	1	2.0		2.0	2.75
Cultivate (disk narrow)	1		1	25	6	2.4		2.4	3.30
Seed winter cover crop	1			18	1	.6			.08
Disk in cover crop seed	1		1	25	1	.4		.4	.55
Supervision						2.4			.60
Miscellaneous [3]						2.8	2.0		.60
Total						14.4	4.8	4.8	8.70

[1] Trees set 60 by 60 feet, or 12 to the acre, of which 5 per cent were missing, 93 per cent were in bearing, and 2 per cent were not in bearing—mainly replants.
[2] Ordinary labor at 12½ cents an hour, supervision at 25 cents, horse work at 12½ cents, and tractor at $1.25.
[3] Includes manuring, hoeing, spraying, orchard sanitation, and miscellaneous operations.

TABLE 42.—*Alabama, Eufaula district: Annual cost per acre of operating pecan orchards 15 to 19 years old* [1] *according to a common method and at cost rates prevailing in 1928, and yield required to cover costs*

Item	Quantity	Cost
Labor and power prior to harvest:	*Hours*	*Dollars*
Man labor	14.4	2.10
Horse work	4.8	.60
Tractor work	4.8	6.00
Total		8.70
Materials:	*Pounds*	
Fertilizer at $28 per ton	285	3.99
Winter cover crop, vetch at 12 cents per pound	18	2.16
Miscellaneous [2]		1.35
Total		7.50
Other costs:		
Taxes		.75
Use of machinery, not including tractor [3]		.18
Overhead [3]		2.43
Total		3.36
Total cost, exclusive of interest		19.56
Interest at 6 per cent [3]		7.44
Total cost, including interest		27.00
Quantity of nuts at 30 cents per pound [4] required to cover cost including harvesting:		
Exclusive of interest	74	
Inclusive of interest	100	

[1] Trees set 60 by 60 feet, or 12 to the acre, of which 5 per cent were missing, 93 per cent were bearing, and 2 per cent were replants and not in bearing.
[2] Includes manure, spray material, paint, and other materials.
[3] See p. 16 for method of computing machinery, overhead, and interest charges.
[4] The 1928 State average farm price. Harvesting costs include picking, grading, delivery to local shipping point, and are based on pecans sold through a cooperative association.

Conditions affecting pecan yields in the Eufaula district are similar to those outlined in the discussion of the Selma district, with a comparable degree of variation in yields obtained from different orchards in 1928. Yields reported for orchards 10 to 19 years of age ranged from 14 to 300 pounds an acre.. One-half of these orchards from which production records were obtained by personal visits did not have yields sufficient to cover costs, including interest charges and harvesting costs, computed on the basis of the common method of operating pecan orchards in the district. As in the Selma district, and for the State of Alabama as a whole (Table 8), the 1928 yields in the Eufaula district were relatively favorable compared with those of other seasons.

Cotton has long been, and still is, the chief cash crop in the district centering around Eufaula. With decreased cotton yields, caused by the advent of the boll weevil and in some cases by the depletion of soil fertility, considerable attention is being given to pecan planting with a view to supplementing the income from cotton, or in some cases as a major commercial enterprise intended to furnish all or a large part of the farm income in the future.

Here, as in the other districts, it is well to remember that conditions that handicap one crop may also militate against any new crop introduced. It is fully realized by most farmers that pecan trees, like cotton, are affected by diseases, insect pests, and adverse weather conditions, but many persons fail to realize that soil fertility is just as important for growing successful pecan orchards as for the successful production of cotton or other crops. The location of some

orchards in this district, as well as in other districts, without giving due consideration to soils, has resulted in the development of trees that are now severely handicapped in their ability to produce economic yields. The leadership of the more successful orchardists in the area may well be followed in adopting practices which, in conjunction with proper location, will be more likely to result in profitable yields. These practices may have to be modified to meet conditions existing in different orchards. The profitable yields obtained in the better managed orchards in the district are proof of the possibilities of a well-planned system to meet the requirements of pecan trees.

MISSISSIPPI

GULF COAST DISTRICT

The orchards studied in the Gulf coast district of Mississippi are about equally divided between Harrison and Jackson Counties. This district is the only one studied in which interplanted crops for harvest are not commonly grown in young orchards. Truck crops and filler crops of Satsuma oranges are interplanted in only a few orchards. Because of other competing industries and, in part, the close proximity of the Gulf coast resort section, wages for man labor are relatively high. These two factors (no interplanted crop for harvest and high wages) cause a relatively high total cost of developing orchards into bearing in this district. The entire orchard is usually plowed in the spring; fertilizer is scattered around the trees and disked in with the first cultivation. Only tree rows are cultivated. The centers are allowed to grow weeds which are turned under with the spring plowing. The tree rows are cultivated about four times during the summer. Spraying and the use of cover crops are not common.

TABLE 43.—*Mississippi, Gulf coast: Labor and power costs per acre of developing a pecan orchard during the first 10 years, according to a common method* [1] *and at cost rates prevailing in 1928*

Operation	Years operation is performed	Size of crew			Rate of work per day	Times done each year	Man labor	Horse work	Tractor work	Cost
		Men	Horses	Tractors						
		Number	*Number*	*Number*	*Orchard acres*	*Number*	*Hours*	*Hours*	*Hours*	*Dollars*
Plow	First	1	2		1.5	1	6.7	13.4		3.52
	Second to tenth	1		1	4	1	22.5		22.5	33.19
Harrow (disk)	First	1		1	15	1	.7		.7	1.03
Plant:										
Set stakes	do	3			25	1	1.2			.27
Dig holes	do	2			7	1	2.9			.65
Set trees	do	5	2		14	1	3.6	1.4		1.02
Apply fertilizer around trees.	First and second	3	2		50	1	1.2	.8		.39
	Third	3	2		40	1	.8	.5		.25
	Fourth	3	2		32	1	.9	.6		.29
	Fifth	3	2		28	1	1.1	.7		.35
	Sixth	3	2		24	1	1.2	.8		.39
	Seventh	3	2		22	1	1.4	.9		.45
	Eighth	3	2		20	1	1.5	1.0		.49
	Ninth	3	2		18	1	1.7	1.1		.55
	Tenth	3	2		16	1	1.9	1.2		.61
Cultivate tree rows (disk harrow).	First to tenth	1		1	40	4	10.0		10.0	14.75
Prune	Second to tenth						8.5			1.91
Remove pruned wood.	Fifth to tenth						3.1	6.2		1.63
Supervision	First to tenth						19.5			8.78
Miscellaneous [2]	do						27.5	25.9		10.07
Total							117.9	54.5	33.2	80.59

[1] Trees set 60 by 60 feet, or 12 to the acre. No interplanted crop for harvest during the development period.

[2] Includes spraying, seeding cover crop, orchard sanitation, and replacing missing trees.

The fact that row crops are not generally grown in pecan orchards in this district accounts in a large measure for the use of tractor-drawn equipment for plowing, harrowing, and cultivating the orchards. At rates prevailing in 1928 the total labor and power cost for the first 10 years was about $80 an acre. (Table 43.)

During the first year of development the cost of labor and power, trees, commercial fertilizer, spray, cover-crop seed, taxes, interest, and other items chargeable to the trees, plus the value of the land on which the trees were set, amounted to approximately $84 an acre. At the end of the tenth year the total cost, including interest compounded annually, plus the value of the land at $50 an acre, amounted to about $312 an acre. (Table 44.)

TABLE 44.—*Mississippi, Gulf coast: Cost per acre of developing a pecan orchard for the first 10 years, by years, according to a common method and at cost rates prevailing in 1928*

Item	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	Ninth year	Tenth year
Fertilizer—pounds	24	24	36	60	84	108	132	156	180	204
Labor and power:										
Man labor—hours	24.1	8.6	9.2	8.2	10.4	11.8	12.1	11.9	11.5	10.1
Horse work—do	19.9	1.6	1.6	2.1	4.4	5.8	6.2	5.0	4.5	3.4
Tractor work—do	1.7	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Labor and power:	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
Man labor [1]	6.32	2.25	2.41	2.16	2.72	3.11	3.17	3.13	3.02	2.66
Horse work at 15 cents per hour	2.99	.24	.24	.32	.66	.87	.93	.75	.68	.51
Tractor work at $1.25 per hour	2.12	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37
Total	11.43	6.86	7.02	6.85	7.75	8.35	8.47	8.25	8.07	7.54
Materials:										
Trees at $1 each	12.00									
Fertilizer at $37 per ton	.44	.44	.67	1.11	1.55	2.00	2.44	2.89	3.33	3.77
Miscellaneous [2]	1.54	1.37	.31	1.32	1.79	1.65	2.01	3.49	2.91	2.78
Total	13.98	1.81	.98	2.43	3.34	3.65	4.45	6.38	6.24	6.55
Other costs:										
Taxes	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Use of machinery [3]	.77	.10	.14	.18	.65	.96	1.21	.71	.88	.32
Overhead [3]	3.81	1.30	1.20	1.39	1.66	1.80	1.94	2.19	2.15	2.11
Total	5.58	2.40	2.34	2.57	3.31	3.76	4.15	3.90	4.03	3.43
Total cost, exclusive of interest	30.99	11.07	10.34	11.85	14.40	15.76	17.07	18.53	18.34	17.52
Interest at 6 per cent [3]	3.24	5.09	6.07	7.08	8.41	9.91	11.56	13.06	15.04	16.79
Total cost	34.23	16.16	16.41	18.93	22.81	25.67	28.63	31.59	33.38	34.31
Cost of development at end of each year [4]	84.23	100.39	116.80	135.73	158.54	184.21	212.84	244.43	277.81	312.12

[1] Ordinary labor charged at 22½ cents an hour and supervision at 45 cents an hour.
[2] Includes spray material, cover-crop seed, trees for replanting, and other materials.
[3] See p. 16 for method of computing machinery, overhead, and interest charges.
[4] Total cost including interest plus initial value of land, at $50 per acre.

As previously stated, the general practice of not growing interplanted crops for harvest during the development of the young orchard is a large factor in causing the relatively high cost per acre of developing young orchards in this district compared with costs in other districts. A large number of the orchards are owned by persons who derive the main portion of their incomes from other sources, and who can not always devote the time and attention, or the supervision, that would be required by the interplanted crops, mainly

truck crops, which are adapted to the district. Cotton, which would require less attention, is not favored by the soil and climatic conditions near the Gulf coast. Many of the orchards are owned by absentee landlords and are operated by caretakers for a fee. These orchards are not usually interplanted to commercial crops.

In general, the cultural system commonly followed for bearing orchards is much the same as for the development of young orchards. The entire tract is plowed in spring. Usually, about three cultivations with a disk harrow are given during the summer. The use of cover crops or spray is not common. Rather heavy applications of commercial fertilizer are made, usually following the spring plowing and just preceding the first disking.

The care of an acre of bearing orchard in the Gulf coast district usually requires slightly more than 2.5 days of man labor and the necessary motive power to perform the field operations. Tractor-drawn implements are commonly used for plowing and cultivating. The labor and power cost, not including harvesting the crop, was $14.40 an acre. (Table 45.) The total 1928 operating cost, exclusive of harvesting costs, is shown in Table 46. Harvest costs in 1928 varied from $1.50 to $3.75 per hundred pounds of nuts.

TABLE 45.—*Mississippi, Gulf coast: Annual labor and power cost per acre of operating pecan orchards 15 to 19 years old* [1] *up to harvest time, according to a common method, and at cost rates prevailing in 1928* [2]

Operation	Size of crew			Rate of work per day	Times done	Man labor	Horse work	Tractor work	Cost
	Men	Horses	Tractors						
	Number	*Number*	*Number*	*Orchard acres*	*Number*	*Hours*	*Hours*	*Hours*	*Dollars*
Prune	1			1.5	1	6.7			1.51
Remove pruned wood	2	2		10	1	2.0	2.0		.75
Plow	1		1	4	1	2.5		2.5	3.69
Apply fertilizer around trees	3	2		14	1	2.1	1.4		.68
Cultivate (disk harrow)	1		1	15	3	2.0		2.0	2.95
Supervision						4.4			1.98
Miscellaneous [3]						6.6	3.2	.7	2.84
Total						26.3	6.6	5.2	14.40

[1] Trees set 60 by 60 feet, or 12 to the acre, of which 5 per cent were missing, 88 per cent were in bearing, and 7 per cent not in bearing—mainly replants.

[2] Ordinary labor at 22½ cents, supervision at 45 cents, horse work at 15 cents, and use of tractor $1.25.

[3] Includes applying manure, harrowing, mowing weeds, hoeing, seeding cover crop, spraying, and miscellaneous operations.

TABLE 46.—*Mississippi, Gulf coast: Annual cost per acre of operating pecan orchards 15 to 19 years old,[1] according to a common method and at cost rates prevailing in 1928, and yield required to cover costs*

Item	Quantity	Cost
Labor and power prior to harvest:	*Hours*	*Dollars*
Man labor	26.3	6.91
Horse work	6.6	.99
Tractor work	5.2	6.50
Total		14.40
Materials:	*Pounds*	
Fertilizer at $37 per ton	400	7.40
Miscellaneous [2]		4.00
Total		11.40
Other costs:		
Taxes		1.00
Use of machinery, not including tractor [3]		1.08
Overhead [3]		3.87
Total		5.95
Total cost, exclusive of interest		31.75
Interest at 6 per cent [3]		19.18
Total cost		50.93
Quantity of nuts at 30 cents per pound [4] required to cover cost including harvesting:		
Exclusive of interest	118	
Inclusive of interest	186	

[1] Trees set 60 by 60 feet, or 12 to the acre, of which 5 per cent were missing, 88 per cent were in bearing, and 7 per cent not in bearing—mainly replants.
[2] Includes spray, manure, cover-crop seed, and other materials.
[3] See p. 16 for method of computing machinery, overhead, and interest charges.
[4] The 1928 State average farm price. Harvesting costs include picking, grading, and delivery to local shipping point and are based on pecans sold to buyers by express.

Pecan yields obtained in Mississippi in 1928 were considerably above the average for other years, as indicated by the November 1 crop-condition reports obtained for a period of years. (Table 8.) However, the information obtained by means of personal visits and by questionnaires indicates a wide range in yields from different orchards in the Mississippi Gulf-coast district. Yield information for 1928 was obtained from 43 orchards 15 to 19 years of age, including 16,037 trees. The range in yields from these orchards is shown in the distribution of the orchards classified according to the average yield secured per tree.

Yield per tree in pounds	Number of orchards	Yield per tree in pounds	Number of orchards
0.5–4.49	12	32.5–36.49	4
4.5–8.49	6	36.5–40.49	2
8.5–12.49	3	40.5–44.49	3
12.5–16.49	2	44.5–48.49	1
16.5–20.49	2	48.5–52.49	0
20.5–24.49	0	52.5–56.49	2
24.5–28.49	3	56.5–60.49	2
28.5–32.49	1		

Approximately 28 per cent of the orchards yielded less than 4.5 pounds of pecans a tree and 42 per cent yielded less than 8.5 pounds of pecans a tree. On the basis of 12 trees to the acre, of which 10.6

are in bearing, approximately 56 per cent of the pecan orchards 15 to 19 years of age did not have yields sufficient to pay costs in 1928, including harvest costs and interest charges, based on the common method of operating bearing orchards in the district. With costs computed on the same basis, but not including interest as a charge, approximately 48 per cent of the orchards did not have yields sufficient to pay costs. On the other hand, comparatively high yields were reported from some of the orchards, as indicated in the upper ranges of the yield distribution shown.

The most common reasons given for the low yields obtained on some of the orchards were the use of varieties unsuited to the district; lack of soil fertility; poor drainage; uncontrolled insect pests and fungus diseases; trees planted too close; and neglect of the orchard during the development period. Although these and other factors discussed for the other districts must be given due consideration, differences in orchard sites with respect to soil fertility and surface features are one of the most important factors contributing to the wide range in pecan yields in this district. The soils vary widely in their ability to produce profitable pecan crops. The flat, poorly drained gray soils are of low agricultural value. In other sections of the district, the red, waxy clay subsoil, often nearly impervious, is too close to the surface to permit easy cultivation. The most successful orchards in the district are on well-drained sandy-loam soils having subsoils of friable yellow or reddish sandy or fine sandy clays.

LOUISIANA

SHREVEPORT DISTRICT

The orchards studied in the Shreveport district of Louisiana are in Caddo, Bossier, and Natchitoches Parishes, the majority being in the first two parishes. Development of pecan orchards in this district is usually in conjunction with the production of field crops for harvest. The usual practice is to interplant field crops between the trees up to and including the tree rows. Although corn, hay, and vegetables are sometimes used, cotton is the usual crop. Cotton is commonly interplanted for four successive years, alternating with some other crop the fifth year. The interplanted crop is given the usual cultivation just as if the pecan trees were not present. The cultivation given the pecan trees, then, is incidental to that given the interplanted crop. The general practice of interplanting row crops, grown by share labor in orchards during the development stage as well as in bearing orchards, is a large factor in the choice of horses or mules as the common source of motive power for orchard work in this district.

To protect the young trees from injury while cultivating the interplanted crops, two stakes are set, one on each side of the young trees. These stakes are left for four or five years, or until the young trees are not so susceptible to injury. Some growers use screening or burlap wrapping around the lower part of the tree trunks to prevent rabbits from injuring and possibly killing the young trees by girdling them, but this practice is not common.

The proportionate share of the joint costs chargeable to pecans for each year of the development period is shown in the footnotes to Tables 47 and 48. The total labor and power cost for the first 10 years is shown in Table 47, and the total cost, exclusive of the cost or value of the land and the interest thereon, in Table 48.

TABLE 47.—*Louisiana, Shreveport district: Labor and power costs per acre of developing a pecan orchard during the first 10 years, according to a common method* [1] *and at cost rates prevailing in 1928*

Operation	Years operation is performed	Size of crew		Rate of work per day	Times done each year	Percentage charged to pecans	Charged to pecans		Cost
		Men	Horses				Man labor	Horse work	
		Number	*Number*	*Orchard acres*	*Number*	*Per cent*	*Hours*	*Hours*	*Dolls.*
Plow	First to tenth	1	2	1.5	1	[2] 5–18	6.8	13.6	2.38
Harrow	do	1	1	7	2	[2] 5–18	2.9	2.9	.73
Plant:									
Set stakes	First	3		30	1	100	1.0		.15
Dig holes	do	1		3.5	1	100	2.9		.44
Set trees	do	7	2	24	1	100	2.9	.8	.52
Stake trees	do	2	2	8	1	100	2.5	2.5	.62
Cultivate	First to tenth	1	1	3.5	[3]	[2] 5–18	15.8	15.8	3.95
Hoe around trees	First and second	1		20	4	100	4.0		.60
	Third	1		18	2	100	1.1		.16
	Fourth	1		18	4	100	2.2		.33
	Fifth and sixth	1		17	4	100	4.8		.72
	Seventh	1		16	4	100	2.5		.38
	Eighth	1		16	2	100	1.2		.18
	Ninth and tenth	1		15	4	100	5.4		.81
Prune	Second to tenth					100	5.8		.87
Remove pruned wood	Fifth to tenth					100	2.8	5.6	.98
Supervision	First to tenth					100	18.3		5.49
Miscellaneous [4]	do					100	27.2	7.0	4.78
Total							110.1	48.2	24.09

[1] Trees set 66 by 66 feet, or 10 to the acre. Cotton usually rotated with corn or some other cultivated crop for harvest, interplanted up to and including the tree rows during the entire development period.

[2] Charges for land preparation and cultivation charged to pecans as follows: First year, 5 per cent; second year, 5 per cent; third year, 6 per cent; fourth year, 7 per cent; fifth year, 9 per cent; sixth year, 10 per cent; seventh year, 12 per cent; eighth year, 14 per cent; ninth year, 16 per cent; tenth year, 18 per cent.

[3] Pecan trees cultivated the same as the interplanted crops for harvest on the basis of six cultivations for cotton and three for corn and other cultivated crops for harvest.

[4] Includes fertilizing, spraying, seeding cover crop, orchard sanitation, and replacing missing trees.

TABLE 48.—*Louisiana, Shreveport district: Cost per acre of developing a pecan orchard for the first 10 years, by years, at cost rates prevailing in 1928*

Item	First year	Second year	Third year	Fourth year	Fifth year	Sixth year	Seventh year	Eighth year	Ninth year	Tenth year
Labor and power:										
Man labor, hours	18.8	7.2	6.8	8.0	9.4	10.4	11.8	9.8	13.6	14.3
Horse work, do	5.4	2.1	2.5	3.4	3.8	4.2	5.8	5.4	7.4	8.2
Labor and power:	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*	*Dolls.*
Man labor [1]	3.28	1.26	1.18	1.40	1.65	1.82	2.07	1.71	2.39	2.51
Horse work, at 10 cents per hour	.54	.21	.25	.34	.38	.42	.58	.54	.74	.82
Total	3.82	1.47	1.43	1.74	2.03	2.24	2.65	2.25	3.13	3.33
Materials:										
Trees, at $1.10 each	11.00									
Stakes for young trees, at 6 cents each	1.20									
Miscellaneous [2]	1.10	1.07	.27	1.61	.29	1.12	2.16	.40	.44	1.24
Total	13.30	1.07	.27	1.61	.29	1.12	2.16	.40	.44	1.24
Other costs:										
Taxes [3]	.08	.08	.09	.10	.14	.15	.18	.21	.24	.27
Use of machinery [4]	.20	.08	.09	.13	.14	.16	.22	.20	.28	.31
Overhead [4]	2.57	.38	.26	.50	.35	.50	.72	.40	.54	.69
Total	2.85	.54	.44	.73	.63	.81	1.12	.81	1.06	1.27
Total cost, exclusive of interest	19.97	3.08	2.14	4.08	2.95	4.17	5.93	3.46	4.63	5.84
Interest at 6 per cent [3] [4]	.51	1.70	2.08	2.44	3.01	3.47	4.12	4.90	5.60	6.41
Total cost	20.48	4.78	4.22	6.52	5.96	7.64	10.05	8.36	10.23	12.25
Cumulative cost [5]	20.48	25.26	29.48	36.00	41.96	49.60	59.65	68.01	78.24	90.49

[1] Ordinary labor charged at 15 cents an hour, supervision at 30 cents an hour.

[2] Includes fertilizer, cover-crop seed, spray material, trees for replanting, and other materials.

[3] Charges for taxes and interest prorated to pecan trees as follows: First year, 5 per cent; second year, 5 per cent; third year, 6 per cent; fourth year, 7 per cent; fifth year, 9 per cent; sixth year, 10 per cent; seventh year, 12 per cent; eighth year, 14 per cent; ninth year, 16 per cent; tenth year, 18 per cent.

[4] See p.16 for method of computing machinery, overhead, and interest charges.

[5] Does not in this case include any sum for initial value of land.

At the end of the first year of the development period the cost of labor and power, trees, commercial fertilizers, cover-crop seed, spray, and other items chargeable to the trees was about $20 an acre. At the end of the tenth year the "cumulative cost," including interest compounded annually, amounted to approximately $90 an acre. (Table 48.) Land values in this district are higher than in the other districts studied. The rich alluvial soil produces especially good yields of cotton not only during the development stage of the orchard but also in orchards of bearing age. Such land as is usually used for pecan orchards is commonly valued at $150 an acre.

Field crops are usually interplanted in bearing orchards. A few growers leave tree-row spaces which are cultivated independently of the intercrops. The most common method, however, is to interplant crops up to the trees in orchards 15 to 19 years of age. The trees receive the same cultivation that is given the intercrops. The system is the same as that used in young orchards. Bearing trees, however, require more space and therefore shade out more of the intercrop than do young trees. Little or no production is expected from intercrops near the trees, although the entire space, up to the trees, is cultivated in the same way. Cotton is the chief field crop.

The labor and power cost, chargeable to pecans, not including harvesting the crop, is shown in Table 49, and the total 1928 operating cost chargeable to pecans, in Table 50.

TABLE 49.—*Louisiana, Shreveport district: Annual labor and power cost per acre of operating pecan orchards, 15 to 19 years old, up to harvest time, according to a common method* [1] *and at cost rates prevailing in 1928* [2]

Operation	Size of crew		Rate of work per day	Times done	Percentage charged to pecans	Charged to pecans		
	Men	Horses				Man labor	Horse work	Cost
	Number	*Number*	*Orchard acres*	*Number*	*Per cent*	*Hours*	*Hours*	*Dollars*
Prune	2		10	1	100	2.0		0.30
Remove pruned wood	2	2	20	1	100	1.0	1.0	.25
Orchard sanitation					100	1.0	.5	.20
Plow	1	2	1.5	1	35	2.3	4.6	.80
Harrow	1	1	7	2	35	1.0	1.0	.25
Cultivate	1	1	3.5	6	35	6.0	6.0	1.50
Hoe	1		8	2	100	2.5		.38
Supervision					100	4.2		1.26
Miscellaneous [3]					100	5.4	4.7	1.28
Total						25.4	17.8	6.22

[1] Trees set 66 by 66 feet, or 10 to the acre, of which 6 per cent were missing, 88 per cent were in bearing, and 6 per cent were not in bearing—mainly replants.

[2] Ordinary labor at 15 cents an hour, supervision at 30 cents, horse work at 10 cents, and use of tractor at $1.25.

[3] Includes seeding cover crop, spraying, applying fertilizer and manure, and miscellaneous operations.

TABLE 50.—*Louisiana, Shreveport district: Annual cost per acre of operating pecan orchards 15 to 19 years old* [1] *according to a common method and at cost rates prevailing in 1928, and yield required to cover costs*

Item	Quantity	Cost
Labor and power prior to harvest:	*Hours*	*Dollars*
Man labor	25.4	4.44
Horse work	17.8	1.78
Total		6.22
Materials: Miscellaneous [2]		2.25
Other costs:		
Taxes [3]		.52
Use of machinery, not including tractor [4]		.79
Overhead [4]		1.27
Total		2.58
Total cost, exclusive of interest		11.05
Interest at 6 per cent [3 4]		8.80
Total cost		19.85
Quantity of nuts at 27 cents per pound [5] required to cover cost, including harvesting:	*Pounds*	
Exclusive of interest	48	
Inclusive of interest	83	

[1] Trees set 66 by 66 feet, or 10 to the acre, of which 6 per cent were missing, 88 per cent were in bearing, and 6 per cent were replants and not in bearing.
[2] Includes cover-crop seed, spray material, fertilizer, and manure.
[3] 35 per cent of the charges for taxes and interest is charged to pecans.
[4] See p. 16 for method of computing machinery, overhead and interest charges.
[5] The 1928 State average farm price. Harvesting costs include picking, grading, and delivery to local shipping point and are based on pecans sold to local dealers.

Harvesting costs in 1928 ranged from $1.50 to $3.50 per hundred pounds of nuts.

In orchards 10 to 19 years of age for which production records were obtained, yields ranged from 54 to 126 pounds an acre. Approximately 50 per cent of these orchards did not have yields sufficient to cover costs, including interest and harvesting costs, as shown in Table 50.

The 1928 yield of pecans in Louisiana was above the average for the State during the 10-year period 1920–1929. Yields reported for that year in the Shreveport district, however, were somewhat lower than anticipated in many of the orchards from which production records were obtained by personal visits. These low yields may be attributed largely to poorly filled nuts.

Most of the orchards included in this study are on cotton plantations or on farms on which cotton is the main, and in some cases the only other, cash crop of importance. The production of pecans, being incidental to the production of cotton even after the orchard has attained bearing age, may not receive the attention that would be accorded a crop that enjoys a more prominent place in the farming system. Yields of pecans for many orchards in the district, therefore, have been somewhat low.

The alluvial soil of the area, on which the larger number of the orchards studied are located, is well adapted to cotton. The normally favorable cotton yields have resulted in a relatively high evaluation of the land. The investment is such, then, that it is particularly desirable that some income be derived from the land pending the development of pecan trees. The planting of fewer trees to the acre not only permits the interplanting of field crops in the orchard during

the development period but also allows a continuation of this practice until the size of the trees prevents a profitable production of such crops. This point in most cases has not been reached in orchards of from 15 to 19 years of age. When the size of trees becomes such that it is no longer advisable to grow an interplanted crop of cotton the sole income from the land, of an initial value of $150 an acre, will be from pecans.

It is an open question whether pecans can successfully compete with cotton on land of this value. The small quantity of nuts required to pay costs as shown in Table 50, represents orchards in which the trees have not attained a size that prohibits the growing of cotton in the orchard and in which the cotton crop is charged with the major share of the joint costs. The general system of orchard management followed, with the yields secured, on an orchard of 30 years of age is outlined briefly as an indication of a system of management followed on older orchards in the district in which cotton is no longer interplanted.

The cultivation of this orchard consists of plowing strips, 15 feet wide, on each side of the tree rows during winter. Beginning in the spring, these strips are gone over with a disk cultivator about every other week until the latter part of July. The middles are allowed to grow up in sweet clover, mostly *Melilotus indica*, which reseeds itself annually. This leguminous growth is disked in during the first part of July, and the entire orchard is usually given two more diskings between that time and harvesting. The sweetclover from one-fourth of the orchard acreage is harvested for hay each year. Fertilizing and spraying are done only irregularly and may not be classed as yearly operations.

During the 5-year period 1924 to 1928 the orchard produced an average annual yield of about 163 pounds of nuts an acre. This was an average yield of 23.6 pounds of pecans a tree, counting all trees originally planted as bearing trees. The orchard was originally planted at the rate of 6.9 trees to the acre, but it was estimated that approximately 28 per cent of the trees were missing and approximately 5 per cent were nonbearing replants. The trees actually in bearing, therefore, produced an annual average of 35.2 pounds of nuts a tree during the 5-year period. The large proportion of missing trees and the consequent lower yield on an acre basis may largely be attributed to neglect of the orchard during the development period. With a full stand of but 7 trees to the acre, the orchard would probably not be crowded for space when 30 years old and with careful consideration given to the maintenance of soil fertility, it is not unreasonable to assume that yields of 30 to 35 pounds normally might be obtained a tree.

MARKETING

In discussing pecan marketing it is important to keep in mind that the so-called improved varieties, under present conditions, are handled in a manner that is different from the manner in which the native seedling crop is handled. Most of the pecans grown under cultivation are of the improved or named varieties which have been selected from the native seedling stock because of size or other desirable qualities. The average size of native seedling nuts is smaller than of the improved varieties.

Improved varieties of pecans are largely marketed and distributed in the unshelled state to consumers. Some seedlings, particularly the largest sizes, are also marketed in this way, but the larger portion of the native seedling crop is sold to commercial shellers. In so far as practicable, therefore, the marketing of improved varieties is discussed separately from the marketing of the native seedling crop.

The marketing information in this bulletin is based on the findings of a survey made in 1928–29. With the assistance of the Federal Farm Board, the National Pecan Marketing Association, a cooperative sales agency, was organized in July, 1930. Pecan-marketing conditions may be affected materially by this organization.

SHIPPING-POINT PRACTICES

Various methods have been used by growers of improved pecans during recent years in disposing of their crops. These include selling through a cooperative association; selling to one of a number of large shippers or to a small local buyer; consigning to a city dealer or retailer; and selling direct to city dealers, retailers, or consumers. Some growers and small shippers have made a practice of selling direct to consumers and shipping by parcel post or express. Most of the sales by large shippers are on an f. o. b. shipping-point basis.

Seedling or native pecans, which are produced chiefly in Texas, Oklahoma, and neighboring States, are usually shelled commercially, although some unshelled seedlings reach the consuming public, principally in mixed nuts. The crop is assembled through country merchants, dealers, and representatives of shellers. The shellers usually buy the nuts ungraded and grade them before cracking.

The methods of disposal of the 1928 pecan crop by growers as reported in the survey are shown in Table 51.

TABLE 51.—*Disposition growers made of the pecan crop, by States, 1928*

State and section	Production	Delivered to cooperative selling association	Shipped to outside buyers by—			Sold locally to—		Cracked on farms for sale of kernels	Consumed on farm	Not disposed of when report was made	Total crop
			Freight	Express	Parcel post	Dealers	Consumers				
	1,000 lbs.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
North Carolina	690	5.6	2.0	7.0	8.0	17.0	16.0	1.0	40.0	3.4	100
South Carolina	730	15.0	5.0	11.0	9.0	19.5	12.0	.5	25.0	3.0	100
Georgia	8,400	24.3	15.8	11.1	4.1	25.9	5.1	.2	12.5	1.0	100
Florida	2,000	24.0	15.0	14.0	4.0	21.0	5.0	.5	15.0	1.5	100
Alabama	3,500	31.3	7.0	15.0	3.0	16.7	10.0	.2	15.0	1.8	100
Mississippi	6,500	7.5	18.0	13.0	3.0	34.0	11.0	.5	10.0	3.0	100
Eastern	21,820	19.5	14.2	12.4	3.9	25.8	8.2	.4	13.7	1.9	100
Missouri	300	.5	3.0	.2	1.3	53.0	28.7	-------	12.7	.6	100
Arkansas	1,750	-------	1.0	15.0	3.0	49.0	11.0	2.0	15.0	4.0	100
Louisiana	5,500	1.0	18.0	2.0	.3	60.0	5.0	.3	10.0	3.4	100
Oklahoma	8,400	-------	13.0	1.0	2.0	64.0	8.5	.5	10.0	1.0	100
Texas	29,500	2.0	7.0	1.5	2.0	67.0	11.0	3.5	5.0	1.0	100
Western	45,450	1.4	9.2	2.0	1.8	64.8	9.9	2.5	7.0	1.4	100
Total	67,270	7.3	10.8	5.4	2.5	52.1	9.4	1.8	9.1	1.6	100

In 1928 handling by cooperative selling associations was largely confined to the States east of the Mississippi. Very few nuts were so handled in any of the States west of the Mississippi and none, so far as reported, in Arkansas and Oklahoma. The most important marketing channel used by growers has been through the local buyers or dealers who are estimated to have handled more than half the crop.

A few growers and small shippers have been successful in marketing pecans by parcel post, but in general it has been difficult to dispose of large quantities successfully in this way. Objections are that the purchaser who is usually a consumer does not have an opportunity to inspect the nuts prior to their receipt and shippers have in some instances suffered losses when payment was not required in advance on parcel-post shipments. Pecans are becoming more generally available through the retail stores, and the trend in prices has been downward. These conditions are not conducive to an increased volume of sales through parcel-post channels.

Methods of disposal vary considerably in the different States, depending upon the degree of concentration of the industry. Sales for local consumption, for instance, amounted to as much as one-fourth of the crop in at least one State and more than one-tenth in several others, while it fell to one-twentieth in Georgia, Florida, and Louisiana. Consumption on the farm where produced is also relatively high in districts in which the crop is grown to only a limited extent, being 25 per cent and over in the Carolinas, but falling to 5 per cent in Texas where a large proportion of the crop is not gathered by the owner. Growers' shipments by express are highest in the States east of the Mississippi that produce improved types of nuts, and are negligible in Louisiana, Oklahoma, and Texas.

The rate on less than carload lot freight shipments of unshelled pecans from Albany, Ga., to Chicago, Ill., in June, 1931, was reported as $1.51 per hundredweight, and on car-lot shipments 97 cents per hundredweight. These rates are subject to change and are stated here only as an illustration of approximate transportation costs.

Pecans sold cooperatively or to large shippers in the districts that produce chiefly improved varieties have been sized, graded, and packed at houses operated by the association or by shippers. Of the nuts handled cooperatively or by large shippers in the 1928 season, approximately 50 per cent were packed in 100-pound double-ply burlap sacks, 38 per cent in 50-pound boxes, 9 per cent in 25-pound boxes, and the remainder in barrels, small sacks, and cartons. Reports indicate that somewhat less than one-half of the 1928 crop shipments of unshelled pecans from the improved pecan area were in carloads. The remainder were sent to market chiefly in l. c. l. (less than carload lot) freight shipments although some were moved by express, parcel post, and motor truck.

General grading methods for improved varieties or large seedlings have been recommended by the National Pecan Association, but they have not been applied uniformly by all shippers.[5] Each of the important shipping organizations has operated under its own brands, which represent various varieties or mixtures of varieties, and its own standards of quality and size. In marketing, the Schley variety, which brings a premium in price, is not mixed with other varieties.

[5] Official grading standards for unshelled pecans (improved varieties and large seedlings—not shelling stock) were issued by the Bureau of Agricultural Economics, U. S. Department of Agriculture, in October, 1930, and were recommended by the National Pecan Association at its annual meeting in 1930.

The so-called standard varieties other than Schley, as Stuart, Success, Van Deman, Alley, Pabst, Frotscher, and others of similar appearance and character, are usually sold in mixtures of varieties but in some instances as individual varieties.

Usually pecans from the current season's crop can not be placed on the market in quantity, until after the first of November. In years of heavy production a considerable percentage of the crop has been carried over in cold storage and marketed during the next season. In view of the fact that the pecan crop arrives on the market too late for the October and early November trade it would appear to be sound practice to carry over, under proper cold-storage conditions, a limited quantity to take care of the early fall demand for unshelled pecans. Particularly in years of heavy production a carry-over of moderate size to the next season should relieve the marketing situation.

A large crop usually has been followed the next year by a medium or small-sized crop which facilitates the sale of nuts held over from a large crop. The marketing situation may, of course, be materially weakened if there is an excessive carry-over in the hands of shippers or city dealers. In some years the uncertainty of the quantity carried over, either in the producing area or in scattered holdings in the markets, has been an unsettling factor in the price situation.

SHIPPING-POINT PRICES

Average f. o. b. prices for the crops produced during the period 1925 to 1930 as computed from reports by shippers in the southeastern area are shown in Table 52. The figures for all sales are supposed to represent the average prices for the crops specified, including in some instances returns on nuts carried over and sold during the next fall. The relation between supply and price during these years is difficult to determine. The relatively small crop of improved varieties in 1925 sold at the highest price received in any of the six years, but the large crop of 1926 apparently averaged more per pound than did the light crop of 1927. Considerable quantities of the 1926 crop, however, were not sold until the fall of 1927. The large 1928 crop (exclusive of nuts carried over until the fall of 1929), according to reports, averaged slightly higher in price than did the 1927 crop. The smaller 1929 crop influenced by the carry-over from 1928 averaged about the same in price as the crop sold the previous season.

If full and accurate information were available to shippers at the beginning of each marketing season regarding the size of the current crop and the quantity carried over from the previous season at shipping points and in the markets, it should be possible to determine a scale of prices at which the current crop, or a certain percentage, would move into consumption. Less uncertainty as to the price situation would materially benefit the industry as a whole.

The premium in price of Schley over other standard varieties has ranged from 12 to 18 cents per pound during the period 1925 to 1930. For the 1928 crop the relative quantities of the varieties or groups shown in Table 52 based on the reports covering about 6,000,000 pounds of the improved crop were: Schley, 13 per cent; other standard varieties, 53 per cent; miscellaneous (including some standard varieties), 28 per cent; seedlings, 3 per cent; culls and crackers, 3 per cent.

TABLE 52.—*Approximate prices per pound of pecans (f. o. b. basis) by classes, as reported by shippers in the area east of the Mississippi River, 1925–1930* [1]

Crop	Schley	Other standard varieties [2]	Miscellaneous varieties [2]	Seedlings [3]	Culls	All sales
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
1925	54	36	31	20	15	35
1926	44	32	25	16	19	32
1927	44	31	23	17	15	30
1928	45	32	25	13	14	31
1929	45	33	27	15	7	31
1930	43	29	24	13	6	28

[1] Prices were computed by combining reports and estimates from shippers in the area producing mostly improved varieties. Minor arbitrary adjustments were made in a few instances. They are presented as approximations of the weighted average f. o. b. prices. It was impracticable to obtain weighted average prices for various gradations of quality and size reported by the different shippers. The 1929 figures are influenced by some carry-over from the 1928 crop included in the report of sales.

[2] Standard varieties other than Schley, include Stuart, Alley, Pabst, Van Deman, Success, Frotscher, Delmas, and possibly others. Some nuts of these varieties may be included with "miscellaneous varieties."

[3] Seedlings as here reported include only relatively small quantities reported by shippers who handle chiefly improved varieties.

The reader should keep in mind that the prices shown in Table 52 are the selling prices at shipping point for pecans from the southeastern area. The costs of assembling at shipping points and of grading and packing, and incidental costs, are charges which must be deducted from f. o. b. prices in ascertaining the prices received by growers of these nuts. These costs vary and may range from a few cents to as much as 7 or 8 cents per pound.

Growers throughout the entire pecan belt, who are pecan correspondents of the Division of Crop and Livestock Estimates, were asked to report the prices received for pecans, under the classification of improved varieties and seedlings. These prices, and the total value of the crop by States for the period 1925 to 1931, are shown in Table 53. The prices which growers reported they received for improved varieties are slightly higher than would be indicated by the f. o. b. shipping-point prices reported by shippers. (Table 52.) The reports of growers, however, include sales by parcel post and express and small-lot sales in which the prices received were probably higher than in the case of sales made to dealers or through associations.

The higher price of the improved varieties is noticeable, being usually from two to three times as much as received for the seedling nuts. Seedling nuts from some sections that produce nuts of exceptionally good size and character bring considerably better prices than the average shown for seedling nuts, and some of course bring less; the difference in size and quality of seedling nuts is quite as great as among improved varieties.

Table 53 also shows the total value of the crops of improved and seedling pecans for the years 1925 to 1931 inclusive. It will be seen that Texas derives a larger income from pecans than any other State. The value of pecans in that State, which produces in average years close to one-half of the total crop, ranges from about $1,000,000 to almost $5,000,000. Georgia comes second, with an income ranging from $1,000,000 to almost $3,000,000 annually. Mississippi and Oklahoma have incomes from pecans of around $1,000,000 or more in average years. Alabama and Louisiana usually receive from $500,000 to $1,000,000 each.

TABLE 53.—*Average price per pound of pecans received by pecan growers, and total value of the crop, 1925–1931*

PRICE PER POUND

State	Improved varieties							Seedling varieties						
	1925	1926	1927	1928	1929	1930	1931	1925	1926	1927	1928	1929	1930	1931
	Cts.	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*	*Cts.*
North Carolina	45	44	40	36	34	33	20	30	25	27	22	20	18	14
South Carolina	45	28	35	33	35	28	17	30	21	23	17	20	18	11
Georgia	37	31	34	28	31	30	12	25	15	17	13	15	14	6
Florida	37	30	33	31	33	29	14	22	14	17	16	17	17	8
Alabama	40	34	37	30	30	25	14	25	19	20	13	16	12	8
Mississippi	39	37	38	30	32	27	14	23	18	19	14	17	12	7
Arkansas	34	35	35	32	35	30	15	18	15	15	14	12	12	6
Louisiana	32	32	38	27	31	24	16	17	14	16	10.7	15	12	7.5
Oklahoma	35	30	35	35	39	30.5	19	15	10	13	11	10.2	9.1	5
Texas	34	30	35	35	32	27	17	17	11	16	11.7	11	11	5.3
Illinois	--	--	--	--	--	--	--	17	17	14	15	15	14	8
Missouri	35	32	48	35	30	20	15	18	16	20	16	13	12	8
United States	37.8	32.5	35.4	29.6	31.7	27.8	13.8	17.3	11.8	15.4	11.9	11.4	10.8	5.8

VALUE OF CROP

	1,000 dolls.	*1,000 dolls.*	*1,000 dolls.*	*1,000 dolls.*	*1,000 dolls.*	*1,000 dolls.*	*1,000 dolls.*	*1,000 dolls.*	*1,000 dolls.*	*1,000 dolls.*	*1,000 dolls.*	*1,000 dolls.*	*1,000 dolls.*	*1,000 dolls.*
North Carolina	86	198	152	158	146	139	147	42	82	76	55	47	40	44
South Carolina	166	252	192	182	158	210	136	54	84	46	31	26	31	16
Georgia	1,924	2,449	1,496	2,072	1,116	1,290	938	300	225	102	130	60	56	41
Florida	444	309	264	465	248	261	263	158	68	58	80	42	42	38
Alabama	640	789	363	834	402	582	493	150	148	56	94	45	48	38
Mississippi	936	980	597	975	384	662	420	620	513	310	455	187	390	175
Arkansas	14	32	21	30	21	24	26	275	436	216	232	113	170	158
Louisiana	266	240	133	221	116	288	154	799	735	304	501	319	816	378
Oklahoma	26	30	14	14	27	21	22	2,194	1,960	1,152	920	1,513	1,177	569
Texas	44	252	66	280	176	81	163	2,018	4,517	1,506	3,358	2,140	1,342	1,645
Illinois	----	----	----	----	----	----	----	4	54	13	4	22	28	20
Missouri	2	5	2	2	4	2	5	107	238	79	47	115	71	141
United States	4,548	5,536	3,300	5,233	2,798	3,560	2,767	6,721	9,060	3,918	5,907	4,629	4,211	3,263

DISTRIBUTION OF THE 1928 IMPROVED CROP

Reports from shippers on the primary distribution of about 6,000,000 pounds of unshelled pecans of the 1928 crop from Georgia, Mississippi, Alabama, Florida, Louisiana, North Carolina, and South Carolina indicate that approximately 27 per cent of the shipments went to the North Atlantic States including New England, New York, New Jersey, and Pennsylvania. Primary distribution is shown in Table 54. The primary distribution shows in a general way where the improved pecan crop is consumed (fig. 4), but it must be kept in mind that large quantities are redistributed from such important centers as Cincinnati, Chicago, and New York.

The reports indicate that more than half of the shipments of improved varieties are consumed in the North Central States from Ohio to Kansas, Nebraska, and the Dakotas, but consumption of improved varieties grown east of the Mississippi River is small in Kansas, Nebraska, Minnesota, and in States farther west. That southern pecans are reaching consumers on the Pacific coast to an appreciable extent is shown by the fact that California received 68,000 pounds which is 1.1 per cent of the quantity on which primary destinations were reported. Shipments were reported to 39 States in addition to the District of Columbia and the New England group.

TABLE 54.—*Primary destination of unshelled pecans, by State and division, crop of 1928* [1]

Destination	Quantity	Percentage of total reported
North Atlantic States:	*Pounds*	*Per cent*
New England	202,260	3.3
New York	1,095,855	18.0
New Jersey	24,785	.4
Pennsylvania	300,792	4.9
Total	1,623,692	26.6
North Central States:		
Ohio	1,531,855	25.1
Indiana	211,019	3.5
Illinois	806,087	13.2
Michigan	244,190	4.0
Wisconsin	76,493	1.3
Minnesota	51,405	.9
Iowa	23,857	.4
Missouri	384,599	6.3
North Dakota	3,300	.1
South Dakota	1,950	
Nebraska	81,140	1.3
Kansas	8,520	.1
Total	3,424,415	56.2
South Atlantic States:		
Delaware	400	
Maryland and District of Columbia	210,075	3.4
Virginia	31,774	.5
West Virginia	16,677	.3
North Carolina	26,848	.5
South Carolina	8,200	.1
Georgia	180,124	3.0
Florida	91,126	1.5
Total	565,224	9.3
South Central States:	*Pounds*	*Per cent*
Kentucky	62,345	1.0
Tennessee	92,615	1.5
Alabama	41,360	.7
Mississippi	500	
Arkansas	3,000	
Louisiana	4,950	.1
Oklahoma	42,934	.7
Texas	100,202	1.7
Total	347,906	5.7
Far Western States:		
Montana	1,850	
Wyoming	50	
Colorado	10,672	.2
Arizona	4,325	.1
Utah	5,600	.1
Washington	14,775	.2
Oregon	12,200	.2
California	68,371	1.1
Total	117,843	1.9
Foreign countries:		
Cuba	3,750	.1
Canada	12,680	.2
England	500	
Total	16,930	.3
Grand total	6,096,010	100.0

Compiled from shippers' reports on 6,096,010 pounds.

[1] Pecans from the area producing principally improved varieties. Many shipments to points such as Cincinnati, New York, and Chicago were probably redistributed to cities and towns in near-by States.

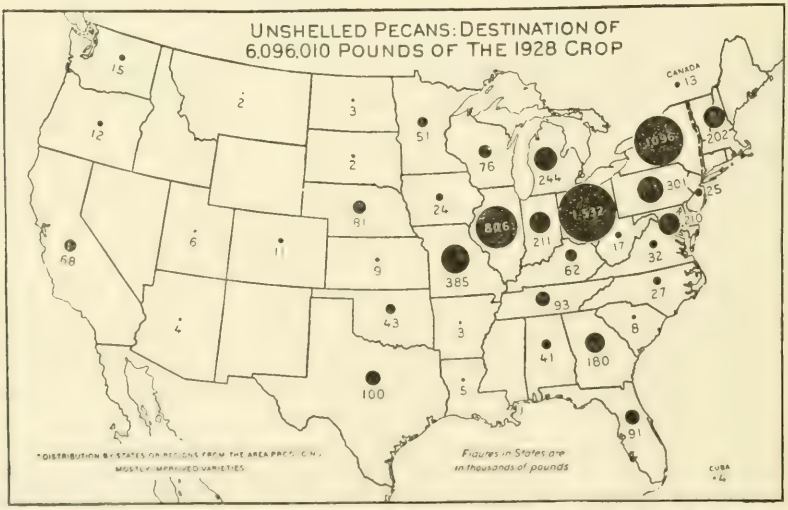

FIGURE 4.—The principal consuming territory for pecans marketed unshelled is in the North Central and North Atlantic States according to reports showing primary destinations of shipments from the southeastern pecan-producing area. (Table 54)

Lack of information on final destinations makes it impossible to ascertain whether distribution is fairly uniform within the various regions shown in Table 54. Information from various sources suggests that the pecan is practically unknown in many small towns and villages in the North.

CITY MARKET SURVEY

Representatives of the Bureau of Agricultural Economics interviewed pecan brokers, wholesalers or jobbers, and retailers in 22 cities, including Boston in the East and Omaha in the West during the period from December, 1928, to March, 1929. The purpose of this market survey was to ascertain the opinions of the wholesale and retail trade on pecan-marketing problems, to collect information on marketing methods and practices, and to receive suggestions for improvement. Two sets of questionnaire forms were used in interviewing city dealers, one for brokers and wholesalers or jobbers (using these last two terms synonymously), and one for retailers.

Information obtained from brokers, wholesalers, and jobbers included data on the quantity and grade of pecans and other nuts handled; origin and jobbing price of pecans; period of year when pecans and other nuts are usually on the market; percentage of sales made during the holiday period; channels of trade; trade preferences as to type of package; methods of transportation and grading; adjustment of disputes concerning quality of receipts; advertising; competition with other nuts; storage; comparison of demand for shelled and unshelled nuts; and direct shipments from producing districts to retailers and consumers. Opinions as to possibility of expanding the markets and of increasing pecan consumption, and suggestions for improving marketing conditions were obtained.

Similar information was obtained by interviews with retailers both in chain organizations and independents in the cities visited. Retailers were also asked questions relating to display practices, consumers' preferences, size of consumers' purchases, and retail prices.

ATTITUDE OF TRADE TOWARD PECANS

For the marketing territory as a whole, brokers, wholesalers, and retailers were practically unanimous in expressing optimism as to the possibility of increasing the consumption of pecans. It was the general feeling that domestic-market outlets could be developed to take care of an increasing annual production. The pecan is recognized by those who are familiar with it as a nut of high merit. Its movement into consumption has not been stimulated by advertising and organized sale policy to the extent that the movement of certain other nuts has been speeded up by these means.

The principal suggestions for improving marketing conditions for unshelled pecans according to this trade survey during the 1928–29 season included: (1) Greater organization and cooperation among pecan growers and shippers (as a result, other means of advancing the welfare of the industry could be carried out more effectively); (2) advertising to acquaint consumers and retailers with the merits of the pecan; (3) improving grading practices, particularly among small shippers, so as to prevent poorly filled and defective nuts from reaching the markets and the consumers; (4) greater control of distribution so as to reduce the quantity of consignments and miscellaneous small

shipments which tend to unsettle prices; and (5) stabilization of prices in relation to the season's supply. Most of the trade believes that if the price margin between pecans and comparable grades of Persian (English) walnuts were narrowed the demand for pecans would be greatly stimulated.

CHANNELS OF MARKET DISTRIBUTION

The principal market receivers of unshelled pecans are wholesale grocers, jobbers, and chain merchandising organizations. The chain stores sometimes buy through jobbers as well as direct from shippers. Large independent retailers often buy from shippers or growers with whom they have established contacts, but the smaller independent retailers buy from the wholesale grocers and jobbers. Considerable quantities have been received on consignment by city jobbers or dealers. These consignments have been mostly from growers or small shippers and sometimes have been received by commission merchants on the fruit and vegetable markets who have not had a regular trade in nuts and have been at a disadvantage in selling such shipments at the price level prevailing in transactions by dealers who handle nuts regularly. The greater part of the crop, however, has been bought on an f. o. b. shipping-point basis. In many instances purchases have been made through brokers who represent shippers in the markets. In some districts consumers who have contacts in the producing areas receive pecans direct by parcel post or in small freight or express shipments. Brokers and the wholesale trade in various cities serve a considerable area in the city's trade territory. In many small towns and villages, however, pecans are little known.

PREFERENCES AND OPINIONS OF THE WHOLESALE TRADE

Large-to-medium sized thin-shelled pecans are preferred by the trade. Although most unshelled pecans that reach the market are of improved varieties, considerable quantities of seedlings are marketed in the shell mostly for use in mixed nuts during the holidays. Reports from wholesalers or jobbers and brokers stating the poundage of improved varieties, and seedlings handled unshelled in the 1928 season, show that 18 per cent of the quantity reported was seedlings. Many of these seedlings came from Texas and Oklahoma. Relatively large quantities of seedlings were reported by dealers in the New England receipts.

In regard to wholesale packages for unshelled pecans it was found that of wholesalers and large retailers canvassed, 35 per cent preferred the 50-pound box, 27 per cent preferred the 25-pound box, and 38 per cent preferred other packages including the 100-pound sack. Arguments in favor of the box were that it gives better protection from damage and pilfering than the sack, and that 25 or 50 pounds is a more suitable quantity for many retailers than is a larger package.

Over 80 per cent of the wholesalers stated that they found it as profitable to handle pecans as other nuts.

There were some complaints from dealers in various markets regarding the grade and quality of some shipments. Some poorly filled pecans, and some improperly cured at the beginning of the shipping season, were reported. Many of these nuts were consignments or receipts from small shippers.

Many handlers in the markets find the large number of brands from various shippers confusing, and believe that greater standardization of grading practices would be to the advantage of the industry. On account of the large number of pecan varieties many dealers believe the practice of mixing varieties of similar characteristics into one lot in marketing is more satisfactory than to keep each variety separate. Some dealers voiced an objection to this practice, however, stating that inferior varieties may easily be included in a mixture or blend.

Disputes which occur between shipper and receiver are mostly settled by private adjustment.

Most members of the wholesale or jobbing trade, and most brokers, believed there will be some narrowing of the price differential between pecans and walnuts or almonds. It was generally felt that if the price differential of 10 or 12 cents a pound were reduced the demand for pecans would be greatly stimulated and an increasing supply could be absorbed by the markets.

RETAIL OUTLETS AND PRACTICES

Observations and answers to inquiries among independent and chain grocery stores in various cities throughout the northern marketing region indicate that, as a general estimate, about one-half of the stores carried unshelled pecans during the 1928 holiday season or for a longer period. Large quantities are handled by chain drug stores and nut specialty stores, and some are handled by department stores. Bulk window display has been used by some stores as an effective means of speeding up pecan sales. Of the managers of chain and independent retail stores interviewed, who carried unshelled pecans, over half reported carrying them for less than three months in the fall and winter. Others carried them four to six months and a few carried them all year. Many retailers reported carrying English walnuts (nuts of *Juglans regia* are meant throughout this discussion) all year. Personal interviews with retailers indicated that from 70 to 85 per cent of the unshelled pecans were sold during November and December. A large majority of the retailers who handled shelled pecans reported them on sale all year, with only about one-third of the annual volume of sales made in November and December.

The majority of retailers interviewed expressed an opinion that the demand for shelled pecans was increasing more rapidly than the demand for unshelled pecans. No definite conclusion, however, could be reached as to whether it would pay shippers to market a considerable part of the improved varieties as shelled stock. The cost of shelling, yield of kernels, and price obtainable would decide whether such a policy would be practical. About two-thirds of the consumers who replied to the survey questionnaire expressed a preference for buying pecans unshelled.

In the city districts which could be classed as medium-to-wealthy, pecans were much more generally used than in the poorer districts. In fact the pecan was generally referred to as a "luxury" nut.

About 50 per cent of the retailers interviewed stated that the average size of consumers' purchases of unshelled pecans is 1 pound. A considerable number of retailers reported from 1 to 5 pounds as the usual sale and some reported one-fourth to 1 pound. For shelled pecans many retailers reported sales of one-fourth pound as the usual quantity.

Seventy per cent of the retailers interviewed, including chain-store managers, stated that they bought pecans more than once during the season. A common practice with retailers is to display unshelled pecans in the original sack or box, or in a bin in bulk. Practically all retailers said that their trade preferred to buy pecans from bulk rather than in a closed package. The 50-pound and 25-pound boxes seemed to be the wholesale packages most popular with retailers. Most retailers stated that only a few consumers recognized any varieties of pecans, and none recognized brands. Size and thickness of shell are the principal factors considered by the average consumer in purchasing pecans.

Retail prices observed in various cities during the 1928–29 season generally ranged from 60 to 90 cents per pound on medium-to-large Schley pecans. A few quotations below and above these figures were noted. Prices on other standard varieties ranged generally from 40 to 60 cents, with an average close to 50 cents. Some medium-to-large seedlings were being offered at 30 to 45 cents. Shelled pecans were observed on sale at the rate of 90 cents to $1.50 per pound.

Prices of nuts have been fairly stable during most seasons according to the majority of retailers. During the winter and spring, however, some retailers as well as wholesalers reduce prices, particularly in years when large supplies are on hand.

The majority of retailers interviewed thought the demand for pecans would be equal to or greater than the demand for English walnuts and almonds if the price of pecans per pound were the same as the price of these other nuts. Nearly all retailers stated that pecan consumption among their customers is increasing. Retailers in general thought that advertising in magazines, newspapers, or by radio and the free distribution of recipe pamphlets to customers would show practical results in stimulating demand.

PECAN MARKETING CONDITIONS IN CERTAIN LARGE MARKETS

Pecan marketing practices and conditions which prevailed in certain large markets during the 1928 season are here described:

NEW YORK, N. Y.

Practically all brokers, jobbers, and retailers in New York City agreed that there is an upward trend in pecan consumption and that there are excellent possibilities of increasing the quantity of pecans used in the city and near-by points.

The greater part of the improved pecans used in the New York district come from Georgia, although there are some receipts from other States. Some carloads of seedlings from Texas and Mexico are received for use in mixed nuts and a few carloads for shelling.

Pecans are bought by the jobbers, wholesale grocers, and large retailers either through brokers or direct from shippers. Most of the small retailers buy unshelled pecans in small quantities from local jobbers. Wholesale grocers are instrumental in distributing both unshelled and shelled nuts throughout the city's trade territory. The bulk of New York's pecan supply arrives in l.c.l. shipments, although some full carloads are received. Some pecans are shipped on consignment to fruit and vegetable commission men in New York who do not make a practice of handling nuts. This is generally conceded to be unsatisfactory, for dealers who do not have an established

nut trade frequently have to sacrifice these receipts at low prices. Such consignments thus have a tendency to unsettle prices. Some pecans are received by independent retailers direct from shippers but as compared with the quantity handled through jobbers, wholesale grocers, and chain stores, this quantity is relatively small.

Most of the grocery stores in the sections occupied by people of medium and large incomes carry unshelled pecans during the late fall months, but in the sections where the poorer population lives the pecan is not well known.

Managers of chain grocery stores in the New York district, operating 4,012 retail units, were interviewed. Of these, 1,356 retail units or about one-third were reported as carrying unshelled pecans at some time during the 1928–29 season. An average of about 60 pounds per store was reported for the chain retail units that handle pecans in the shell. The stores located in the more prosperous districts handle many more pecans per store than do those in the poorer districts.

A survey of small independent grocery, fruit, and delicatessen stores in one of New York's poorer districts disclosed the fact that the poorer classes are not familiar with pecans. In the district from Ninetieth Street to One hundred seventh Street and from First Avenue to Third Avenue, of 100 such stores which carried nuts of some kind, only 3 carried unshelled pecans; 2 others had pecans in the mixed-nut stock. Seventy-five of these 100 stores displayed English walnuts; 51 had almonds; 41, filberts; 29, chestnuts; and 16, Brazil nuts. Considering the independent grocery stores in the city as a whole probably about the same proportion of them as units of chain stores handled pecans—that is, one-third.

Pecans were found on sale in some department stores, some 5-and-10-cent stores, and some drug stores. Where conspicuously displayed as specialties in these stores an excellent demand and large turnover were reported. There are several small chains of stores in New York City that make nuts a specialty and handle no other commodity. These stores, which use volume display of nuts both shelled and unshelled, are a decided factor in bringing nuts to the attention of the public.

Most of the New York retail stores reported that they carry unshelled pecans only from October to March and that a large majority of the annual sales are made during the holiday season. Many wholesalers and retailers reported that over 75 per cent of their sales of unshelled pecans were made in November and December.

The proportion of the season's business on shelled pecans handled during these months was reported as less than 50 per cent. Stores that carry shelled pecans usually have them on sale during the whole year.

Practically all stores that sell pecans also sell other kinds of nuts such as walnuts and almonds. For unshelled nuts, the quantity of walnuts handled by retail stores was practically always reported as larger than the quantity of pecans handled. The quantity of almonds was usually larger. The retail price of pecans was usually 10 to 25 cents per pound higher than the retail price of walnuts or almonds. Most wholesalers and retailers expressed the opinion that if the price of pecans were on a level with that of walnuts or almonds, at least as large a quantity of pecans could be sold as of any of these other nuts.

There was some difference of opinion as to whether the demand was increasing more rapidly for shelled or unshelled pecans. The majority of retailers thought the demand for shelled pecans was increasing more rapidly.

As to type of package preferred for unshelled pecans, many New York dealers and retailers mentioned the 25-pound box as being desirable.

Improved varieties were observed to retail in New York in December, 1928, mostly at 39 to 59 cents a pound. Some smaller pecans were retailing as low as 29 cents a pound and in the more prosperous districts large-sized Schley nuts retailed at 75 to 95 cents a pound. Pecan kernels were handled by some retail grocery stores mostly in tin cans of about 3-ounce or 8-ounce capacity or in 5-pound cartons. Retail prices for pecans in these containers ranged approximately from 90 cents to as high as $1.75 a pound.

There were complaints from a few New York dealers regarding the quality and grading of pecans. On the whole, however, the quality and grading were reported as fairly satisfactory.

The consensus of opinion of retailers was that consumers do not generally know varieties or brands of pecans.

Some dealers make a practice of carrying unshelled pecans over in cold storage for use early in the fall before the current season's crop is available.

Jobbers stated that sales are sometimes made by shippers direct to retailers at prices several cents below that at which the jobber could sell and claimed this practice caused them to lose interest in handling pecans.

It was generally felt that various forms of advertising would help to stimulate the demand for pecans and that some lowering in the price level of pecans as compared with other nuts would greatly increase the demand.

CINCINNATI, OHIO

Opinion was unanimous among those interviewed that the Cincinnati district can be further developed as a pecan market. Cincinnati is an important distributing center for a wide territory, and a rapid increase in the quantity of pecans handled was indicated by reports from merchandizing organizations.

Buying from shippers direct by retailers is an important market factor and caused many wholesalers or jobbers in Cincinnati not to stock pecans. The quantity received by consumers direct from shippers was estimated as very small. Most of the unshelled pecans were reported as coming from Georgia.

Two local chains of grocery stores handled pecans in all of their 30 stores. These stores averaged 175 pounds per store of unshelled pecans during the season to January, 1929. Twenty-seven of these stores carried one grade of pecans which they sold at 49 cents per pound. Three stores carried three varieties at three prices: Schley at 80 cents per pound, Stuart at 60 cents, and Moneymaker at 50 cents. These same 30 stores sold an average of about 365 pounds of English walnuts per store for the season to January, 1929. Only 3 of the 30 stores sold almonds; they averaged about 333 pounds each.

Three stores of this group handled shelled pecans and sold a total of 3,500 pounds for the season. Their sales of walnut kernels totaled 2,800 pounds, and of shelled almonds, 200 pounds.

In a canvass of 39 stores in the downtown district of Cincinnati in January, 1929, including stores of 3 national chains and 2 local chains, 17 carried pecans in some form; unshelled pecans were found in 16 stores, and shelled pecans in 11 stores. These stores all catered to customers of moderate means.

A member of one chain of 5-and-10-cent stores carried pecans both shelled and unshelled. This store sold 600 pounds of unshelled pecans during November and December, 1928, at a price of 49 cents per pound, and 150 pounds of shelled pecans at a retail price of $1.30 per pound. It stocks shelled pecans from October to April, selling one-half of the total volume during November and December. No department stores in Cincinnati reported selling pecans, either shelled or unshelled. One chain of drug stores handles unshelled pecans, using them as a specialty and featuring window displays in volume. The manager stated that he planned to handle more in the future. Various soda fountains and news stands carried salted pecan halves in small packages which sold at 10 cents each.

The chain stores as a whole are probably representative of all the stores in Cincinnati, but the ones consulted were probably above the average in quantity handled when all stores are considered. Most of the stores consulted were those catering to people of moderate to liberal means.

Retail grocery stores had pecans on sale over varying periods, ranging from two months to all year. Drug stores handled them only during the holiday season. The 5-and-10-cent store interviewed reported all its sales as occurring during November and December.

Shelled pecans were carried all year by most of the stores handling them. The soda fountains reported a light all-year business; the 5-and-10-cent stores reported sales from October to April.

Retailers are divided in opinion as to the most suitable size of package for pecans, although the majority favor the 50-pound box. Two stated that 100-pound sacks are satisfactory. A local chain-store manager said that a 10-pound package would be most suitable for his needs if a package smaller than 100 pounds were used, otherwise he would prefer a 100-pound sack or a 180-pound barrel. For shelled pecans, all preferred a bulk package, several specifying a 50-pound package containing ten 5-pound cartons.

It appears that the customer prefers to buy from bulk, both shelled and unshelled stock. One man reported success with a 1-pound cloth bag of unshelled pecans but stated that he found it necessary to keep one or two open to allow examination by customers.

There was no agreement as to whether the demand is increasing more rapidly for shelled than for unshelled pecans. The manager of the drug-store chain, (who handled only unshelled stock) reported his belief that the demand for unshelled pecans was increasing more rapidly. The official of the 5-and-10-cent store, who handled both, stated that shelled pecans were being favored. One local chain-grocery manager who handles a large volume thought the demand for shelled stock was increasing more rapidly. The buyer for a large chain with stores outside Cincinnati as well as in the city said the demand for unshelled pecans was leading by a narrow margin.

There were a number of complaints regarding poorly filled nuts, and one complaint of rancid pecans in the shell.

That chain stores carry pecans and that local drug stores make displays with prices posted doubtless have had their effect in stabilizing

retail prices of unshelled pecans. Shelled pecans showed a rather wide range in price for the same quality, selling from 90 cents to as high as $1.50 a pound.

All local store managers stated that advertising would help increase consumption; one suggested that advertising in local newspapers and offering recipe books to customers would help. On the whole, the storekeepers appeared doubtful of the value of recipe pamphlets.

CHICAGO, ILL.

Chicago is one of the most important pecan markets. Brokers estimated that about 1,000,000 pounds of improved varieties of unshelled pecans came into the Chicago district during the 1928–29 season. It was estimated that more than 200,000 pounds, including some seedling stock, came into the South Water fruit and vegetable market on consignment. Those well acquainted with the industry expressed the belief that there is abundant opportunity for developing and increasing pecan consumption in the Chicago district.

Much of the pecan distribution in Chicago is handled through brokers, although some large users buy direct from shippers. Parcel-post and small freight or express shipments to retailers and consumers form a considerable item.

The majority of the retail stores in Chicago handled some unshelled pecans in the 1928–29 season, but stores in the poorer sections were visited which did not handle them at any time during the year. Most of the retail stores handled shelled pecans. Intelligent opinion was that many stores in the small towns in the Chicago district do not carry unshelled pecans even during the holidays.

A large chain-grocery organization with stores in and around Chicago reported an average sale of about 50 pounds of improved varieties of unshelled pecans per store during the 1928 season and about 65 to 75 pounds of kernels per store. The unshelled nuts were on sale only from the middle of November until after the holidays. The buyer for this concern thought it best to emphasize nuts during this period and not carry them through a long season. He believed, however, that a limited quantity might be carried over in cold storage to advantage and put on the market earlier than usual in the fall. Most stores of this chain handled some pecans both in the shell and shelled. The shelled pecans were sold during the entire year.

Walnuts are sold in much larger quantities than are pecans, and more almonds are sold than pecans. If prices of pecans were more nearly on a parity with prices of these nuts, most handlers think the demand would at least equal the demand for these other nuts.

Some retail prices observed in March, 1929, in Chicago, were 40 to 45 cents per pound for improved varieties other than Schley and 59 cents per pound for Schley. Earlier in the season prices were somewhat higher. Fancy pecan halves from improved varieties were retailing in March from $1 to $1.98 per pound. Seedling halves could be bought at retail for 85 cents to $1.10 per pound.

There was a considerable quantity of spotted and poorly filled stock on the Chicago market from the 1928 crop. Dealers said that it would benefit the industry to have pecan grades defined by the Department of Agriculture and used by the trade. The large quantity

of pecans coming into the market on consignment and often sold at reduced prices was pointed out as a weakness in the pecan-marketing situation.

Large quantities of seedling pecans are shelled in Chicago

ST. LOUIS, MO.

St. Louis is recognized as one of the greatest pecan centers in the world. Several of the largest shellers in the industry are located there. The pecan is by far the most popular and best known nut in this trade district, and practically all dealers and retailers believe that the quantity used will continue to increase. Considerable quantities of unshelled seedlings and of improved varieties are retailed, but the improved varieties are gradually replacing the seedlings. Probably more shelled pecans are sold at retail in St. Louis than pecans in the shell. Commission merchants receive a considerable quantity of unshelled pecans.

Many of the improved pecans come into St. Louis in l. c. l. freight lots, although some car lots are received. It was generally thought that the parcel post and small express business in this district was not large enough to figure much in the marketing situation.

Practically every retail grocery store in St. Louis carries unshelled pecans during the holiday season and many carry them during the winter months. Few Schley pecans are used. It was stated that the small towns in the St. Louis neighborhood still use seedlings chiefly. Most stores carry shelled pecans the year round. They are usually put up in 5-pound cartons and sold loose. Chain and independent store managers representing 1,200 to 1,300 units in and around St. Louis stated that practically all stores handle pecans. Reports from certain groups of chain stores indicated average sales for the season of about 30 pounds of unshelled pecans per store and about 60 pounds of shelled pecans. Perhaps 80 per cent of the pecans in the shell and 50 to 60 per cent of the shelled pecans retailed in this district were sold during the fall. One important nut retail store in St. Louis sold 15,000 to 20,000 pounds of improved varieties of pecans during the 1928 season. This illustrates what can be accomplished by specializing, and by bulk display. The manager of this store stated that it does not pay to operate the year round as the natural season for nuts is limited to the fall and winter months. Some of the drug stores and department stores handle pecans.

Retail prices in St. Louis for Stuart and other improved varieties, (except Schley) ranged mostly from 39 to 49 cents per pound for the 1928 crop. Seedling halves retailed mostly at 69 to 75 cents in the spring of 1929. In March, 1929, retail prices observed in a nut specialty shop were as follows: Pecans in the shell (large Schley), 75 cents per pound; English walnuts, 40 cents; almonds, 30 cents; Brazil nuts, 35 cents; filberts, 30 cents. For shelled nuts the prices were: Pecans (seedling halves), 75 cents per pound; pieces, 70 cents; large salted and roasted pecan halves, $1.25; English walnuts, 95 cents; almonds, 75 cents; almonds (salted), $1.25; Brazil nuts, 95 cents; black walnuts, 95 cents.

Some dealers expressed dissatisfaction with the grading of pecans. They stated that many poorly filled nuts of certain varieties are received. Miscellaneous consignments and sales by small shippers and growers were mentioned as factors that often weaken the marketing situation.

CHAIN-STORE AND CONSUMER SURVEY BY MAILED QUESTIONNAIRES

To ascertain conditions existing in the retail trade and the retailers' opinions regarding marketing pecans and other nuts, and as a check against information obtained by interviews with retailers, questionnaires were mailed to local chain-grocery stores or branches of national chains in cities in all sections of the country. Replies covering all or part of the questions were received from 73 organizations representing 9,325 stores.

To ascertain the consumers' preferences, the uses made of pecans and other nuts, prices paid, and other pertinent information, questionnaires were mailed out to 6,000 persons whose names were obtained from directories in about 60 cities of various sizes throughout the United States. Only about 350 replies were received from this inquiry, but the answers to most of the questions were in close agreement, so it is believed the results give a fair picture of certain phases of pecan marketing from the consumers' point of view. It is probable that many of those who failed to answer the consumers' questionnaire were those who were not very familiar with pecans or other nuts. Those who replied probably used more than the average quantity.

Information regarding retail prices, period during which nuts are on sale, and other phases of marketing was also obtained through these mail inquiries from the chain stores and the consumers. The replies to chain-store and consumer questionnaires will be discussed separately. The replies to some questions were tabulated by geographical sections to indicate differences that may exist in different sections of the country.

RESULTS OF CHAIN-STORE SURVEY BY MAIL

In answer to the question as to whether there was any pronounced upward trend in pecan consumption among their customers, 45 chain-store organizations replied that there was, and 17 that there was not. Fifty-one chain-store organizations stated that pecan consumption per capita was decidedly higher in the wealthy districts of their cities than in the poorer districts. Seven stated that it was not.

As to the method used in purchasing pecans, 34 chain-store organizations reported that they usually bought in l. c. l. lots f. o. b. shipping points; 19 reported that they bought in l. c. l. lots on a delivered basis; whereas 9 reported car-lot purchases either f. o. b. or delivered.

Of those answering the question as to size and type of package preferred, 9 favored the 100-pound bag; 12, the 50-pound box; and 6, the 25-pound box.

Preference for large-sized pecans was expressed by 29 chain organizations compared with 18 that prefer medium-sized pecans. Preference for cartons as a container for pecan kernels was expressed by 12 organizations, compared with 14 preferring tins, and 4 preferring glass jars.

Thirty-nine chain organizations believed the demand was increasing more rapidly for shelled than for unshelled pecans; 16 believed it was not.

Reporting the composition of mixed nuts they handled, 23 out of 32 chain-store firms stated that pecans were included.

In response to requests for comments on marketing pecans and other nuts with suggestions for improvement, 7 replies from chain stores suggested advertising as a method of increasing sales; 10 suggested improvement in grading practices; 2 suggested lengthening the selling season; and 3 expressed the opinion that the price level has been too high.

An average of the poundage handled per store of various nuts in the shell, reported by chain stores during the 1928 season, was obtained. These averages were computed by dividing the poundage reported for each kind of nut by the number of stores handling that particular kind. The averages were as follows: Improved varieties of pecans, 50 pounds; almonds, 118 pounds; English walnuts, 322 pounds; filberts, 67 pounds; Brazil nuts, 140 pounds; mixed nuts, 149 pounds. (Table 55.) There was considerable variation in the quantity reported per store in various geographical areas. For example, in the South Atlantic States the average per store was 87 pounds of improved pecans, whereas in the far Western States the average reported was 28 pounds. If all chain stores, including those which did not handle these nuts, were included, the average poundage of each kind of nut per store would be considerably less than here indicated. A few stores reported sales of more than 1,500 pounds of improved pecans per store.

TABLE 55.—*Average quantity of specified kinds of unshelled nuts reported sold by each chain store during the season, 1928*

Region from which reports were received [1]	Pecans (improved varieties)	Almonds	English walnuts	Filberts	Brazil nuts	Mixed nuts
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
North Atlantic	51	63	354	56	102	126
North Central	48	92	280	71	105	162
South Atlantic	87	131	315	59	127	166
South Central	36	164	192	63	114	213
Far Western	28	141	467	87	250	77
Average	50	118	322	67	140	149

[1] The States from which replies were received as grouped in this and other tables relating to chain-store and consumers' questionnaires are as follows: North Atlantic—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania; North Central—Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, North Dakota, South Dakota, Iowa, Nebraska, Missouri, Kansas; South Atlantic—Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida; South Central—Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, Texas; far Western—Montana, Wyoming, Idaho, Colorado, Utah, Nevada, New Mexico, Arizona, Washington, Oregon, California.

The period during which nuts are offered for sale during the season is an important factor in marketing. Reports from chain stores indicated that 83 per cent of the season's sales of improved pecans and 86 per cent of the unshelled seedlings were sold during October, November, and December, whereas only 56 per cent of the shelled stock was sold during these months. (Table 56.) For certain other unshelled nuts the percentages sold during these months were reported as follows: Almonds, 89 per cent; English walnuts, 80 per cent; filberts, 92 per cent; Brazil nuts, 90 per cent; mixed nuts, 96 per cent. For shelled almonds the percentage reported as sold during these months was 64, and for English walnuts 57.

TABLE 56.—*Average quantity of specified nuts reported sold by chain stores during October, November, and December, 1928, as a percentage of the season's sales*

Classification of nuts	Pecans (improved)	Pecans (seedling)	Almonds	English walnuts	Filberts	Brazil nuts	Mixed nuts
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Unshelled	83	86	89	80	92	90	96
Shelled		56	64	57			

It is evident that most of the sales of unshelled nuts are made during the late fall. For pecans the greater part of the year's sales are made during the six weeks from the middle of November to the end of the year. Sales of shelled nuts are distributed to a larger extent over the whole year. This fact would lend some weight to the argument that more of the improved varieties should be marketed as shelled nuts.

Retail prices during the 1928 season for pecans and certain other nuts in the shell as reported by chain stores were tabulated by geographic regions, and averages of these regional prices were also obtained. Variations in prices among the different regions were not large, as shown in Table 57. The figures indicate that improved pecans sold about 20 cents per pound higher than walnuts and almonds in chain stores. Seedlings sold considerably below these other nuts.

TABLE 57.—*Average retail price per pound, of specified unshelled nuts, as reported by chain stores, 1928 season*

Region from which reports were received	Pecans		Almonds	English walnuts	Filberts	Brazil nuts	Mixed nuts
	Improved varieties	Seedlings					
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
North Atlantic	51	26	34	35	24	28	29
North Central	51	22	29	34	24	27	26
South Atlantic	48	25	34	35	25	27	28
South Central	53	21	28	32	22	27	25
Far Western	52	28	30	30	24	27	30
Average	52	24	31	33	24	27	28

RESULTS OF CONSUMER SURVEY BY MAIL

To ascertain the trend in the use of pecans, consumers were asked if their families used more pecans during the 1928 season than four or five years previous: 206 replied "yes," and 128 "no." (Table 58.) In all sections of the country except the far West an increased consumption was indicated. In the far West those answering in the affirmative and the negative to this question were about equally divided.

TABLE 58.—*Consumers' replies as to whether their families used more pecans in the 1928–29 season than four or five years previous*

Region from which replies were received	Number answering—	
	Yes	No
North Atlantic	53	34
North Central	60	41
South Atlantic	37	13
South Central	34	17
Far Western	22	23
All regions	206	128

Consumers were asked whether they preferred to buy nuts in the shell or shelled. The majority preferred to buy them in the shell. (Table 59.) Preference for unshelled nuts was indicated in each region. The principal reasons mentioned by consumers who preferred to buy nuts in the shell were: They are fresher and have better flavor; they are more sanitary; they will keep better; they are more desirable for table use. The chief reasons advanced by those who favored buying shelled nuts were: It is more convenient and saves the trouble of cracking and extracting the kernels; the purchaser can see the kernels and is better able to judge the quality; more perfect kernels can be obtained, as many kernels break when the nuts are cracked at home; waste due to defective nuts and parts of kernels remaining in the shell is eliminated when shelled nuts are purchased. "It is more economical" was given as a reason by both those who preferred nuts in the shell and those who preferred shelled nuts.

TABLE 59.—*Consumers' reported preference for shelled or unshelled nuts*

Region from which replies were received	Number expressing preference for nuts—	
	Unshelled	Shelled
North Atlantic	55	25
North Central	57	40
South Atlantic	41	10
South Central	38	12
Far Western	29	16
All regions	220	103

Consumers were asked to name, in order of importance, the ways in which they used pecans and almonds. This question was not asked separately for nuts in the shell and shelled. One hundred and seventeen stated that "out of hand" was of first importance; 60 mentioned use in desserts; 59, baking purposes; and 59, use in salads. (Table 60.) "Use in salads" received the highest number of votes for both second and third choice. An important home use of nuts is in candy making, which some probably classed with "baking purposes" in replying to this questionnaire.

TABLE 60.—*Uses of pecans and almonds as reported by consumers in order of importance*

Order of importance	Number reporting uses of pecans and almonds [1]							
	Pecans				Almonds			
	Desserts	Baking purposes	Salads	Out of hand	Desserts	Baking purposes	Salads	Out of hand
First	60	59	59	117	29	45	29	116
Second	54	67	81	40	32	40	41	27
Third	39	23	58	38	20	13	25	16

[1] A considerable number mentioned that they used nuts in making candy. Some probably included this use under "baking purposes."

To learn something about the time of year consumers buy nuts, the question was asked as to whether they purchased nuts at any time except during October, November, and December. This question was asked separately for nuts in the shell and shelled. As an average for all regions 39 per cent stated that they buy unshelled nuts only during these three months; 29 per cent stated that they buy shelled nuts only during these months. (Table 61.) A large part of the nuts pass into consumption during these months as shown by reports from the wholesale and retail trade, but these consumer replies indicate that there is a considerable demand for nuts in other months. It is probable that this "off season" demand could be developed further. It should be kept in mind that the consumers replying to this questionnaire are larger users of nuts and probably use them over a longer season than does the average family.

TABLE 61.—*Percentage of consumers stating that they buy nuts only during October, November, and December* [1]

Region from which replies were received	Unshelled	Shelled
	Per cent	*Per cent*
North Atlantic	31	25
North Central	42	27
South Atlantic	31	39
South Central	57	41
Far Western	37	18
All regions	39	29

[1] The total number of replies was 327.

To gain some idea of consumers' preferences for various nuts they were asked to state their choice, assuming pecans, almonds, English walnuts, filberts, and Brazil nuts sold at the same price. These replies indicate that the pecan is highly favored among nut consumers. (Table 62.) In comparing effective demand, the higher prices which pecans have commanded must be considered. The pecan leads in popularity by a wide margin in the regions in which it is well known as the South Atlantic and South Central regions.

TABLE 62.—*Consumers reporting first choice of specified nuts, assuming the price of all kinds to be the same*

Region from which replies were received	Number reporting as first choice				
	Pecans	Almonds	English walnuts	Filberts	Brazil nuts
	Number	*Number*	*Number*	*Number*	*Number*
North Atlantic	50	7	26	1	3
North Central	63	9	18	1	10
South Atlantic and South Central	76	9	14	0	3
Far Western	20	7	17	1	2
All regions	209	32	75	3	18

Consumers were asked to report the average prices paid during the 1928 season for pecans, almonds, and English walnuts, both in the shell and shelled. In the case of pecans, some purchases of seedling as well as of improved varieties were probably included in the purchases on which prices were reported. According to these reports, consumers of unshelled nuts paid about 12 cents per pound more for pecans than for English walnuts in the 1928 season. In the South Central region a comparatively low price of 34 cents per pound was reported for pecans. In this region relatively large quantities of seedlings are used which would lower the average price for the region. On the whole, however, the price variations among different regions can not be considered as large. (Table 63.)

TABLE 63.—*Average purchase price per pound reported by consumers during 1928 crop season*

Region from which replies were received	Pecans		Almonds		English walnuts	
	Unshelled	Shelled	Unshelled	Shelled	Unshelled	Shelled
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
North Atlantic	50	112	37	102	36	82
North Central	48	96	33	83	37	80
South Atlantic	48	96	39	103	37	85
South Central	34	88	34	94	33	82
Far Western	51	112	36	95	34	71
Average	47	101	36	95	35	80

These prices are in fairly close agreement with the retail prices reported by chain stores (Table 57), which have been discussed. The chain-store report showed prices of 52 cents for unshelled improved pecans and 24 cents for seedlings as compared with the consumers' report of 47 cents for all purchases including both improved varieties and seedlings. The chain-store averages were 33 cents and 31 cents for English walnuts and almonds, respectively, compared with 35 cents and 36 cents reported by consumers. This may indicate that the average of nut retail prices for all stores is slightly higher than the average reported by chain stores.

The average price of shelled pecans was reported by consumers as $1.01 compared with 80 cents reported for English walnuts and 95 cents for almonds. On account of the various containers in which nut kernels are retailed and the difficulty of converting prices paid

to a per-pound basis, it is likely that less dependence can be placed on the prices reported for shelled nuts than on those reported for nuts in the shell.

As a means of learning whether pecans and almonds were generally available to consumers they were asked whether the grocery store that they generally patronized carried these various nuts at any time during the 1928 season. (Table 64.) The replies indicated that in the cities circularized pecans and almonds both in the shell and shelled were available to a majority of city consumers. The figures do not necessarily mean that a large majority of grocery stores carried pecans; only one store out of several in a community may have carried them. The replies may not be representative of the poorer districts.

TABLE 64.—*Number of consumers who stated whether the grocery stores they generally patronized sold pecans or almonds during the 1928 crop season, and whether their purchases of mixed nuts included pecans in the mixture*

Region from which replies were received	Number reporting that their grocery stores, during the 1928 crop season, did or did not sell—								Number stating whether mixed nuts they purchased contained pecans	
	Pecans				Almonds					
	Unshelled		Shelled		Unshelled		Shelled			
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
North Atlantic	53	17	47	19	59	5	44	16	49	15
North Central	85	5	77	10	77	3	63	13	65	18
South Atlantic	47	1	37	1	44	0	34	1	27	10
South Central	43	2	38	3	38	4	22	9	34	7
Far Western	34	7	27	10	40	1	29	6	24	11
All regions	262	32	226	43	258	13	192	45	199	61

Pecans, particularly seedlings, are widely used in mixed nuts. About three-fourths of the consumers who reported buying mixed nuts stated that pecans were included in the mixture, and the other one-fourth stated that pecans were not included. (Table 64.)

To determine how familiar consumers are with pecans they were asked the following questions: Do you know where pecans are grown? Do you know by name any of the larger thin-shelled varieties of pecans? Two hundred and forty-one persons stated that they knew where pecans are grown compared with 88 who did not. Since these replies were from persons who were sufficiently interested in the use of nuts to fill in a questionnaire it is evident that if the entire population were considered a much smaller percentage would be shown to know where pecans are grown. Two hundred and forty-three persons stated that they did not know the names of any of the larger thin-shelled varieties of pecans as compared with 70 who stated that they did.

Three hundred and four persons answered that they would like to receive recipe pamphlets for pecans, almonds, or other nuts if issued free by shippers or growers. Twenty replied that they would not be interested in such pamphlets.

The question was asked: Do you personally find that nuts are a healthful food? Of those replying, 97 per cent answered in the affirmative.

Consumers were asked to state any complaints they might have as to the quality of pecans or almonds, or any comments regarding their use or marketing. Only about one-third of those filling in the questionnaire made complaints or comments in answer to this inquiry. Those relating to pecans included the following: "Too expensive"; "some offered for sale especially in mixed nuts are too small and hard shelled"; "pecans are sometimes dry and of inferior quality"; "old dry nuts are sometimes mixed with new-crop nuts"; "it is difficult to extract kernels of some varieties without loss"; "some pecans are not well filled or carefully graded"; "high-quality pecans are not easy to find"; "display cases in some stores are not dust proof."

THE SHELLING INDUSTRY

A relatively few large shellers handle most of the crop. Important shelling centers are St. Louis, San Antonio, Chicago, and New Orleans. Smaller quantities are shelled at various points throughout this area and the Southeast.

The pecans are cracked mechanically, and the kernels are picked out by hand in the shelling plants. The kernels are often classified according to the approximate number of halves per pound, generally ranging from 750 for the small size to 400 for the large, with some very large ones as low as 220 halves per pound. The pieces of kernels are usually sold separately from the halves. Containers in which many kernels are sold include barrels, 50-pound boxes, 5-pound cartons, 8-ounce cans, 3 to 4-ounce cans. The small cans are vacuum packed. Some glass jars are used.

The poundage of unshelled nuts handled in the 1928 season by shellers replying to an inquiry by the Bureau of Agricultural Economics totaled about 4,000,000 pounds which probably represents less than 10 per cent of the total quantity shelled. The replies received indicate that less than 0.5 per cent of the pecans shelled by these firms were improved varieties. A few nuts were cracked but not shelled and were sold to the retail trade in this way. This quantity was less than 1 per cent of the total. According to the reports the kernels obtained in shelling averaged 38.8 per cent of the unshelled poundage. Of the shelled stock 66.4 per cent was halves, and 33.6 per cent pieces. Average wholesale prices reported by shellers for various sizes of kernel halves for the 1928 season were as follows: 750's, 52.5 cents; 600's, 56.4 cents; 500's, 57.8 cents; 400's, 59.3 cents; pieces, 51.7 cents.

Large quantities of pecan kernels are sold to confectioners. They are also used by the baking trade, ice-cream trade, and salters. Wholesale grocers and chain stores take large quantities for distribution through the retail stores.

COMPETITION OF PECANS WITH OTHER NUTS

Some of the nuts that compete with pecans on the markets are English walnuts, almonds, Brazil nuts, filberts, peanuts, chestnuts, and black walnuts. A number of other nuts (mostly imported) are of considerable importance.

For the 6-year period 1924–1929, the United States annual production of English walnuts averaged about 64,000,000 pounds, compared with about 21,000,000 pounds of almonds, and about 56,000,000 pounds of pecans including both improved varieties and

seedlings. During this period peanut production in the United States (including only nuts which were gathered) averaged about 792,000,000 pounds. Considerable quantities of these peanuts do not reach nut consumers.

Average annual imports of certain nuts for the 6-season period ended June 30, 1930, in round numbers were as follows: Brazil nuts, 30,000,000 pounds; [6] chestnuts, 21,000,000 pounds; English walnuts, unshelled, 19,000,000 pounds; shelled, 20,000,000 pounds; almonds, unshelled, 3,000,000 pounds; shelled, 18,000,000 pounds; filberts, unshelled, 10,000,000 pounds; shelled, 5,000,000 pounds. The imports of pecans, which originate in Mexico, averaged less than 1,000,000 pounds. Most of these were unshelled and were of the small native seedling type. During this period the pecan imports ranged between 2,900,000 pounds for the year ended June 30, 1925, and 124,000 pounds for the year ended June 30, 1930.

Pecans now form a relatively small portion of the total quantity of nuts consumed in the United States. The approximate supply of certain nuts per capita population of the United States is shown in Table 65. In preparing this table production and foreign trade have been considered, but carry-over has been ignored. Shelled nuts have been converted to the unshelled basis. For the five years ended June 30, 1929, the total supply of peanuts including some used for purposes other than human food has averaged about 7 pounds per capita for this period. For the last 5-year period ended in 1929 the per capita supply of almonds, Brazil nuts, filberts, and foreign chestnuts has shown some decrease from the previous 5-year period. The per capita supply of English walnuts has increased slightly.

TABLE 65.—*Annual per capita supply of specified nuts (unshelled basis) in the United States, 1899–1900 to 1929–30*

Period	Pecans	Almonds	English walnuts	Brazil nuts	Filberts	Chestnuts	Total
Average:	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1899–1900 to 1903–04	[a]	0.30	0.41	0.15	0.10	.....	.....
1909–10 to 1913–14	[a]	.52	.71	.20	.14	0.13	.....
1919–20 to 1923–24	0.37	.87	1.00	.33	.25	.19	3.01
1924–25 to 1928–29	.49	.73	1.08	.26	.20	.19	2.95
1919–20	.65	1.02	1.17	.23	.33	.12	3.52
1920–21	.11	.59	.73	.34	.15	.21	2.13
1921–22	.43	.96	1.11	.35	.24	.20	3.29
1922–23	.13	.88	1.03	.35	.25	.18	2.82
1923–24	.51	.90	.99	.39	.26	.24	3.29
1924–25	.35	.79	1.14	.28	.16	.25	2.97
1925–26	.44	.69	1.26	.25	.22	.20	3.06
1926–27	.80	.72	.89	.36	.18	.22	3.17
1927–28	.29	.71	1.26	.11	.22	.09	2.68
1928–29	.56	.74	.91	.31	.20	.17	2.89
1929–30	.40	.62	1.04	.21	.13	.14	2.54

Division of Statistical and Historical Research.

NOTE.—In preparing this table, production, imports, and exports were considered but carry-over was not considered. Imports of shelled nuts were converted to the unshelled basis using the following factors: English walnuts, 42 per cent; almonds, 30 per cent; filberts, 45 per cent. The year extends from July 1 to June 30. Domestic production of chestnuts is not included as figures are not available. The total supply of peanuts, including imports, has averaged 6.97 pounds per capita during the 5-year period 1924–25 to 1928–29. This does not mean that 6.97 pounds per capita were used for human food as some peanuts were used for other purposes. For detailed statistics on exports and imports of various nuts, those interested are referred to the following: GRIES, C. G. FOREIGN TRADE OF THE UNITED STATES, ANNUAL, 1790–1929. NUTS; DOMESTIC EXPORTS, IMPORTS, REEXPORTS AND NET BALANCE, QUANTITY AND VALUE. U. S. Dept. Agr., Bur. Agr. Econ. Rpt. F. S. 51, 35 p., illus. 1930. [Mimeographed.]

[a] Not available.

[6] During the year 1928–29, more than 1,000,000 pounds and in 1929–30 more than 4,000,000 pounds of shelled Brazil nuts were imported and are included in obtaining the average shown.

Various factors may influence the situation with respect to competition among pecans and other nuts but the future position of the pecan in the American markets appears to be good.

SUMMARY

Pecan trees are native to the South Central States. They are found growing abundantly in the alluvial flood plains and delta lands of the lower Mississippi and its tributaries and along the courses of all of the west Gulf rivers. Wild trees are found as far north as the lower Ohio and Missouri Rivers, westward to the margin of the highlands of western Oklahoma and Texas, and southward far into Mexico. Plantings of improved varieties of pecans have been made on a large scale throughout the east Gulf and South Atlantic coastal plains, a large portion of these being in commercial orchards containing thousands of trees each. Trees of improved varieties are now being planted extensively in the native pecan belt where many of the wild seedling trees are being top-worked with scions from improved varieties.

Total production of pecans from 1919 to 1931 has ranged from 10,000,000 to 94,000,000 pounds. Production of improved varieties, coming mostly from planted trees in the Southeastern States, has ranged from 2,000,000 to 20,000,000 pounds. Nuts from seedling and wild trees come mostly from the States west of the Mississippi, and production has ranged from 8,000,000 to 77,000,000 pounds. The eastern pecan States have produced 85 per cent or more of the improved varieties each year since 1919. Georgia frequently supplies about two-fifths of the improved varieties. Texas and Oklahoma together usually produce from a half to four-fifths of the seedling nuts. Texas produces usually from a fourth to a half of the total United States crop of pecans.

The estimated total number of pecan trees in 1929 was about 18,500,000, of which more than 10,000,000 were seedling and almost 8,000,000 were improved types. Of the seedling type about three-fourths were of bearing age. For most improved varieties, trees over 10 years old are considered of bearing age. Of the improved trees about 36 per cent were 10 years old or over in 1929, 22 per cent were from 5 to 9 years old, and about 42 per cent under 5 years.

The most popular improved variety appears to be the Stuart, representing about 30 per cent of all improved pecan trees. The Schley comes next with 19 per cent. Of the total trees reported, 43 per cent were of improved varieties and 57 per cent were seedling or wild.

Production has tended to shift eastward during the last 20 years. Texas and Oklahoma had approximately 77 per cent of the bearing trees in 1910, 56 per cent in 1920, and 48 per cent in 1925. The States east of the Mississippi River had 17 per cent of the bearing trees in 1910, 36 per cent in 1920, and 45 per cent in 1925. Much activity has been shown during late years, both in the Southeast and in the native pecan sections of the Southwest, in the planting of improved varieties.

In view of this heavy planting of young trees and of the increasing bearing surface of the rapidly growing trees 10 to 20 years of age, increase in production should be rather rapid during the next few years, but the amount of the increase will depend upon the attention given the orchards and the extent to which insect pests and diseases

are controlled. Even assuming a mortality as great as 40 per cent in trees under 6 years of age, an increase of about 25 per cent in number of planted trees of bearing age seems likely by 1940. Increase in total production of improved nuts might be as much as 50 or even 100 per cent within the next decade. No material increase in seedling and wild nuts is anticipated. The increase in production of improved and seedling nuts combined during the next decade might amount to as much as 25 or 30 per cent.

Pecan-condition reports, published monthly from July to October, show in the early months no close relationship to the size of the crop, but the relation improves from month to month until in November the reported percentage of a full crop tends to give a rather good indication of the probable size of the crop. Variations in actual production tend to be greater than the condition reports would indicate. The forecasts of probable production published by the United States Department of Agriculture in the fall months, based largely upon reports of correspondents concerning expected production on their own farms, and upon interpretation of the condition reports in the light of the relation of condition to production in previous years, are the best indication of production available while the crop is still being marketed.

Methods and practices in the development of pecan orchards of improved varieties and in the care of bearing orchards have undergone many improvements during recent years. Even though these improvements are rather widely known a considerable portion of the orchards are receiving such indifferent care that the owners can not expect to realize a profit.

In the districts studied, pecan orchards in general are developed in connection with an interplanted cash or feed crop for harvest. The method of cost analysis used assumes that the growing of these intercrops for harvest reduces the cost of certain items required in developing the trees and in producing the nuts in proportion to the land acreage used by the crops grown in the orchard. The evidence would seem to prove that it is good economy to grow intercrops in the young orchard until the space occupied by these crops is needed for the well-being of the mature orchard. Interplanted annual crops for harvest, during the development period, are grown in all districts studied except the Mississippi Gulf coast district and the Mobile district of Alabama. In the latter district, a filler crop of Satsuma oranges is common both in young orchards and in those of bearing age. In the Shreveport district of Louisiana, the practice of growing intercrops is continued in orchards of bearing age.

An analysis in the several districts studied shows considerable variation. The cost of operating bearing orchards of improved varieties, including interest charges, varied among districts from about $20 to $50 per acre. The pounds of pecans required to pay costs, including interest charges, ranged from approximately 80 to 185 pounds per acre. These cost differences are due to a number of reasons, such as wages of man labor, horse-work rates, use of fertilizer, amount of the joint costs that are chargeable to pecans, and the like. The latter is the greatest cost factor. A considerable portion of these costs, however, does not represent actual cash. This is particularly true on farms on which there are enterprises other than pecans. On farms of this class much of the man labor and use of implements and work stock

on the pecan enterprise represents additional use of these things not provided for by the other farm enterprises and therefore should not be classed as additional actual costs to the farmer. In the case of orchards under the management of caretakers, where all the operations are normally hired, the out-of-pocket costs are materially greater.

Pecan trees may bear a few nuts when 3 to 5 years old. Generally speaking, however, they do not come into commercial bearing until about the eleventh year. Yields of pecans have been disappointing even in a favorable year such as 1928. In that year the yield from a great many bearing orchards 15 to 19 years of age in many of the districts studied was not sufficient to cover costs. Among the chief factors that have apparently tended to curtail yields are: Neglect at some portion of the development period; the planting of varieties not adapted to the locality; and selection of a poor site with respect to the ability of the soil to meet the plant-food requirements of the tree. Other contributing factors are improper planting distances and the damaging effect of insect pests and fungous diseases.

Many plantings are set too close for the future welfare of the mature pecan orchard, and some of the trees will need to be removed after a few years of bearing life of the orchard. It is now generally conceded that pecan trees should not be set at the rate of more than 12 to the acre.

Of the fungous diseases affecting pecans, scab is of chief economic importance. Recent observations indicate that the scab fungus is becoming of economic importance on varieties that were formerly thought to be highly resistant, so that the widely followed practice of top-working susceptible varieties to so-called nonsusceptible varieties, may need to be abandoned, and systematic spraying or dusting of varieties subject to scab may need to be adopted.

The so-called improved varieties are largely marketed and distributed unshelled to consumers. The native seedlings are mostly shelled commercially. Improved pecans are sold by growers in various ways such as through a cooperative association, to independent shippers, through commission merchants, to buyers in the markets, or direct to consumers.

Prices of pecans f. o. b. shipping points in the area east of the Mississippi River have varied with varieties and quality and have averaged from 28 to 35 cents a pound for the crops of the period 1925 to 1930.

Reports from shippers indicate that in the 1928 season approximately 27 per cent of shipments from States that grow mostly improved varieties went to the North Atlantic States, 56 per cent to the North Central States, 9 per cent to the South Atlantic States, 6 per cent to the South Central States, and 2 per cent to the far West.

It was the general opinion of brokers, wholesalers, and retailers that domestic outlets could be developed to take care of an increasing annual production. Factors which were suggested as a means of improving pecan marketing conditions were: Greater organization and cooperation among growers and shippers; advertising; improvement of grading practices; greater control of distribution and a reduction in the quantity of miscellaneous consignments; and stabilization of prices in relation to the season's supply.

Improved varieties of unshelled pecans have, according to the 1929 survey, commanded a higher price in the markets than have other

nuts including walnuts and almonds. Most brokers and dealers believed that there will be some narrowing of this price differential.

The survey of pecan-marketing conditions in large cities and the chain-store and consumer survey indicated that the pecan is on sale much more generally in the well-to-do sections than in the poorer sections. Pecans are popular with consumers who are familiar with them. For the area covered in the survey probably less than half of the grocery stores handled pecans in the 1928 crop season. The greater number of the year's retail sales of unshelled pecans are made during the six weeks from the middle of November to the end of the year. The size of consumer purchases is frequently 1 pound. Retail prices of standard varieties other than Schley averaged close to 50 cents a pound in 1928–29.

Pecans that are shelled commercially are used by confectioners, bakers, ice-cream manufacturers, and salters in addition to being retailed to consumers direct. Shellers reported that the average yield of kernels as compared with the weight of the whole nuts is about 38 per cent.

The per capita supply of pecans in the United States (unshelled basis) for the five seasons ended in 1929 averaged 0.49 pound, compared with 1.08 pounds for English walnuts, and 0.73 pound for almonds.

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TECHNICAL BULLETIN No. 323 OCTOBER, 1932

SECOND-GROWTH YIELD, STAND, AND VOLUME TABLES FOR THE WESTERN WHITE PINE TYPE

BY

IRVINE T. HAIG

Associate Silviculturist
Northern Rocky Mountain Forest Experiment Station
Branch of Research, Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - Price 10 cents

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CONTENTS

	Page
Introduction	1
Definitions of terms used	2
Discussion of yield tables	3
Basis and scope	3
Western white pine yields	5
Height growth and site index	6
Number and size of trees	7
Cubic-foot volumes	8
Board-foot volumes	8
Increment and rotation age	12
Predicting the yields of second-growth stands	13
Age determination	14
Site determination	15
Determination of stocking	15
Other features of application	17
Discussion of stand tables	17
Application of stand tables	18
Effect of stocking and composition	18
Discussion of volume tables	19
Yield tables	19
Total stand	19
Trees 6.6 inches d. b. h. and larger	21
Trees 7.6 inches d. b. h. and larger	22
Trees 12.6 inches d. b. h. and larger	22
Dominant stand	24
Stand tables	25
Volume tables	30
Cubic-foot volumes	30
Board-foot volumes, Scribner rule	37
Board-foot volumes, international rule	44
Appendix	54
Yield-table material and technic	54
Statistical analysis of results	59
Stand-table material and technic	62
Volume-table material and technic	63
Literature cited	66

INTRODUCTION

The western white pine type is the most important forest unit over large areas of rough uplands in northern Idaho and adjacent portions of eastern Washington and western Montana. It occupies throughout this region the cooler, moister sites between elevations of 2,000 and 5,500 feet, reaching its best development in northern Idaho between the international boundary and the Lochsa River (*10*).[1] The type is distinguished by its luxuriant growth and great complexity and characterized by the presence of western white pine (*Pinus monticola* D. Don) in association with a large number of other species, principally western red cedar (*Thuja plicata* D. Don), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), lowland white fir (*Abies grandis* Lindl.), western larch (*Larix occidentalis* Nutt.), and Douglas fir (*Pseudotsuga taxifolia* (Lam.) Britt.).

These mixed forests constitute a very desirable natural resource. The stands are unusually dense and the timber yields are large. Moreover, the western white pine and one associate, western red

[1] Italic figures in parentheses refer to Literature Cited, p. 66.

125913°—32——1

cedar, furnish special-use woods of high value. As a result the lumber and allied timber industries in northern Idaho and adjacent timber centers have been built up very largely around the white pine type. These forest industries are locally of great economic importance. In Idaho, for example, where they rank first among the manufacturing industries, they are valued at $100,000,000 and produce annually materials worth $41,000,000; they employ some 18,000 persons and have an annual pay roll of over $22,000,000; and the freight revenue derived from these industries amounts to nearly $11,000,000 a year, an important item in the budgets of the rail carriers of this section (*12*). In addition, the materials produced represent the crop value of some 10,000,000 acres of land in northern Idaho alone, 3,000,000 acres of which is in the western white pine type. This land, because of surface features and climate, is largely unsuited to the production of other crops. In view of these facts the maintenance of forest industries is unquestionably essential to the economic prosperity of northern Idaho and adjacent Washington and Montana.

Future yields of western white pine depend largely upon the control of the white pine blister rust. However, results already obtained from the large-scale experimental control work carried on in the western white pine forests give ample reason to believe that adequate protection from the disease can be realized where such measures are feasible.

Therefore, in view of the rapid depletion of the virgin timber stands on which these forest industries rely (*9*), it becomes increasingly important to know the timber-producing capacity of the large areas of second-growth stands to which the region must turn for raw material within the next half century. It is the purpose of this bulletin to sum up for forest managers and timberland owners the available information on the growth and yield of second-growth western white pine stands. To simplify presentation, the first part of the bulletin contains only the discussion necessary for a proper understanding and application of the tables. Essential supplementary discussion has been relegated to the appendix.

DEFINITIONS OF TERMS USED

The following definitions explain the technical and semitechnical terms used in describing the yield tables.

Diameter breast high.—Diameter at 4.5 feet above the average ground level. Commonly abbreviated as d. b. h. As used in connection with standing trees, this means diameter outside bark.

Basal area.—The basal area of a tree is the area in square feet (including bark) of a cross section taken 4.5 feet above the average ground level. The basal area of a stand is the sum of the cross-sectional areas of the trees composing it. Basal-area values for trees of various diameters are easily obtained from published tables.

Total age.—The age of the oldest dominant tree. This will coincide in most cases with the period elapsed since fire, logging, or other agency removed the previous timber stand.

Even-aged stands.—Stands in which the ages of the youngest and oldest trees are within 20 years of the same age.

Stocking.—The degree to which an area is effectively covered with living trees. Fully stocked or normal stands contain as many trees per acre as can properly utilize the growing space available.

Composition.—The mixtures of tree species forming the stand. Western white pine stands often contain from four to six tree species in widely varying combinations and proportions.

Dominant.—In this study any tree with well-formed crown that receives full sunlight from above and at least some light from the sides. It includes both dominant and codominant as ordinarily defined (*8*).

Site quality.—The relative wood-producing capacity of a given area measured in this study by the height growth of the dominant white pines (*6*).

Site index.—The height attained by the average dominant at 50 years, as a measure of site quality.

Mean annual increment.—The average yearly increase per acre in the volume of a stand, computed by dividing its total volume by its age.

Periodic annual increment.—The average yearly increase in volume per acre over a short period—in this case 10 years.

Utilization standards.—Cubic-foot volumes include the total wood contents of the entire peeled stem, comprising stump and tip but not limbs and bark, for all trees 0.6 inch d. b. h. and larger. Board-foot volumes by the Scribner rule allow for a minimum top diameter of 6 inches for white pine and 8 inches for other species, a stump height of 1 foot for white pine and 1.5 feet for other species, and a trimming allowance of 0.25 foot for white pine and 0.3 foot for other species for each 16-foot log length. Board-foot volumes by the international rule (⅛-inch saw kerf) allow for a minimum top diameter limit of 5 inches and for the same allowance for stump height and trimming as with the Scribner tables. Yield-table volumes are always given in full scale, no allowance being made for possible loss in defect, breakage, or incomplete woods utilization.

Yield.—The wood content per acre measured in some standard unit, such as cubic or board feet. The yields given in these tables are for fully stocked stands and show gross volumes, no allowance being made for defect, loss in breakage, or lack of complete utilization.

DISCUSSION OF YIELD TABLES

BASIS AND SCOPE

The yield tables in this bulletin give the number of trees, the average size of tree, the rate of growth, and the quantity of wood per acre at different ages and qualities of site for even-aged, fully stocked western white pine stands. They are the result of a study begun by the Forest Service in 1909–1912 [2] and reinitiated and completed in 1924–1926 by the Northern Rocky Mountain Forest Experiment Station. In this study the yields of fully stocked, even-aged western white pine stands between 20 and 160 years of age were measured on 306 small sample areas scattered throughout the western white pine type. Figure 1 shows the geographical distribution of these plots. On each sample area the age of stand, site quality, number and size of trees, and quantity of wood in both cubic and board feet were carefully determined. These values were then grouped and averaged

[2] Under the direction of F. I. Rockwell and A. O. Benson. Data on 31 per cent of the plots used were collected by Rockwell, and data on 10 per cent were collected by Benson in the 1909–1912 work.

to show the yields per acre common to each age-site condition. The field and office methods employed in this work have been outlined in

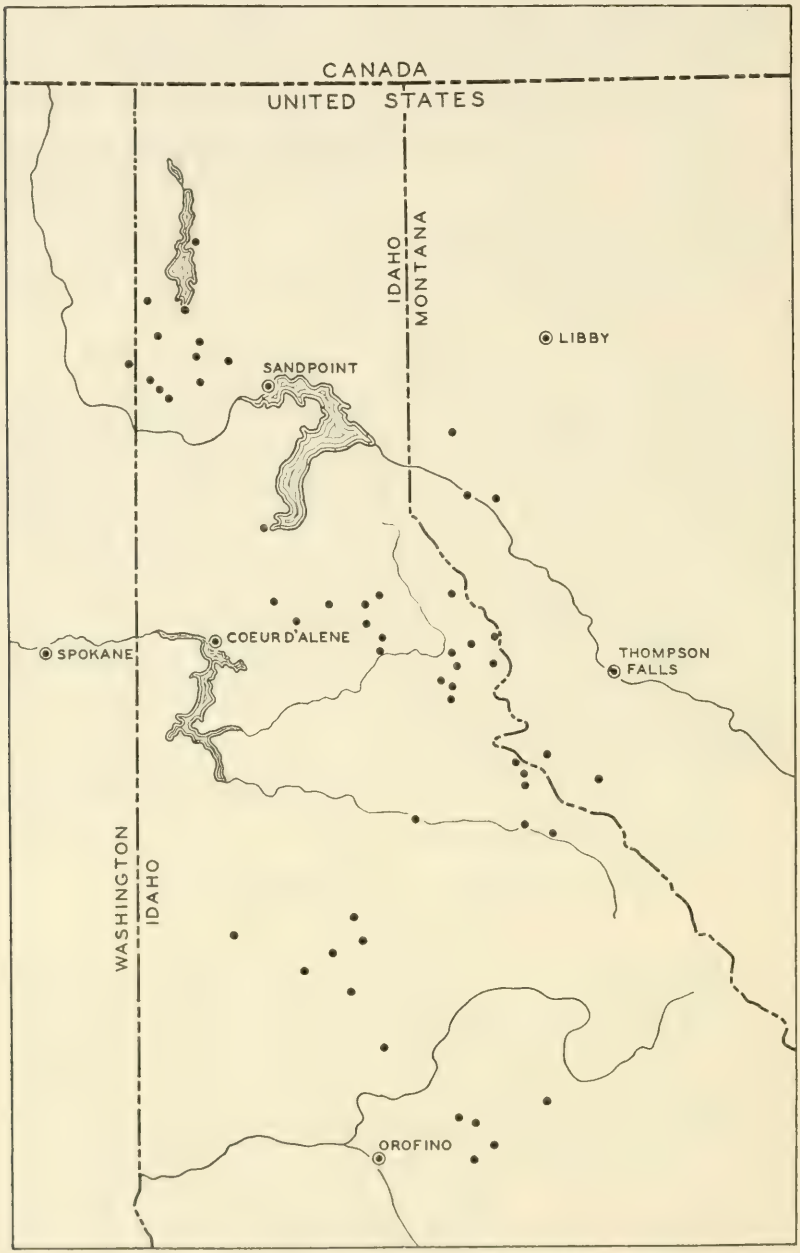

FIGURE 1.—Map showing location of sample plots; each dot marks a locality where one or more plots were taken

detail by other investigators (*15*, *2*) and need not be further elaborated here.

The resulting yield tables are applicable to western white pine stands throughout the entire region described, local differences in rates of growth and yield being accounted for in site-quality differences. The tables are also applicable throughout the region to any stand containing 15 per cent or more of western white pine. Full recognition has been accorded the fact that white pine grows only rarely in pure stands and quite commonly in mixed stands of great complexity and that there is some tendency for certain combinations of species to produce higher or lower yields than other combinations. Nevertheless, these trends are largely obscured by other factors, and a thorough mathematical analysis indicates that the tables presented are, within reasonable limits, applicable to all even-aged western white pine stands regardless of their composition. The tables are directly applicable, however, only to fully stocked stands; i. e., stands with as many trees as can properly utilize the growing space and which are without blanks or holes in the forest canopy. In applying the tables to stands other than fully stocked, the tabular values must be adjusted after the manner described on a subsequent page.

WESTERN WHITE PINE YIELDS

Tables 3 to 24, presented hereafter, constitute a complete set of yield tables, of which Tables 3 to 7 present values for the entire stand; i. e., for all trees in and above the 1-inch diameter class. The remaining tables list partial stand values, or yields per acre for all trees in and above the 7, 8, and 13 inch diameter classes, respectively, and for the dominant stand (all dominant and codominant trees). Each table shows values for one item, for example, number of trees for all age-site conditions. A summary of the values of chief interest is given in Table 1. One of the most interesting features brought out in this table is the characteristic density of fully stocked western white pine stands as indicated by the large number of trees per acre and the relatively small size of the average tree. Note also the rapid growth, averaging on good sites at 120 years some 116 cubic or 760 board feet (international rule) per year, and giving at maturity gross board-foot yields of over 90,000 board feet per acre on good soils over small acreages.

TABLE 1.—*Yields per acre, fully stocked western white pine stands*

POOR SITE—INDEX 40

Total age (years)	Height of average dominant	All trees 0.6 inch plus	Average d. b. h. of trees 0.6 inch plus	Basal area, trees 0.6 inch plus	Total volume				Average yearly growth			
					Trees 0.6 inch plus	International ¼-inch rule		Scribner rule, trees 12.6 inches plus	Cubic-foot, trees 0.6 inch plus	International ¼-inch rule		Scribner rule, trees 12.6 inches plus
						Trees 6.6 inches plus	Trees 12.6 inches plus			Trees 6.6 inches plus	Trees 12.6 inches plus	
	Feet	*No.*	*Inches*	*Sq. ft.*	*Cu. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Cu. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
20	10	11, 500	0. 8	45	240				12			
40	30	5, 600	2. 2	146	1, 890	500			47	12		
60	49	3, 020	3. 6	215	4, 210	7, 500	50	50	70	125	1	1
80	66	1, 830	5. 1	257	6, 500	21, 600	3, 200	2, 300	81	270	40	29
100	79	1, 220	6. 5	286	8, 420	38, 000	11, 000	8, 300	84	380	110	83
120	88	980	7. 6	306	9, 980	51, 000	21, 000	16, 000	83	425	175	133
140	94	910	8. 1	323	11, 000	59, 200	28, 100	21, 000	79	423	201	150
160	98	890	8. 3	338	11, 650	63, 600	31, 700	24, 300	73	398	198	152

TABLE 1.—*Yields per acre, fully stocked western white pine stands*—Continued

FAIR SITE—INDEX 50

Total age (years)	Height of average dominant	All trees 0.6 inch plus	Average d. b. h. of trees 0.6 inch plus	Basal area, trees 0.6 inch plus	Total volume				Average yearly growth			
					Trees 0.6 inch plus	International ¼-inch rule		Scribner rule, trees 12.6 inch plus	Cubic-foot, trees 0.6 inch plus	International ¼-inch rule		Scribner rule, trees 12.6 inches plus
						Trees 6.6 inches plus	Trees 12.6 inches plus			Trees 6.6 inches plus	Trees 12.6 inches plus	
	Feet	*No.*	*Inches*	*Sq. ft.*	*Cu. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Cu. ft.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*
20	12	7,800	1.0	46	320				16			
40	38	3,650	2.7	148	2,270	1,900			57	48		
60	61	2,000	4.5	218	5,050	13,700	1,000	700	84	228	17	12
80	82	1,230	6.2	260	7,750	33,300	8,400	6,500	97	416	105	81
100	99	820	8.0	289	10,100	54,300	25,000	19,200	101	543	250	192
120	110	660	9.3	310	12,000	70,300	44,100	32,200	100	586	268	368
140	117	610	10.0	327	13,250	80,400	55,600	41,000	95	574	397	293
160	122	590	10.3	342	14,000	85,900	60,200	45,500	88	537	376	284

GOOD SITE—INDEX 60

20	14	4,700	1.3	46	400				20			
40	45	2,210	3.5	149	2,650	4,400			66	110		
60	73	1,190	5.8	221	5,880	23,300	5,000	3,700	98	388	83	62
80	98	720	8.2	263	9,000	48,700	24,100	17,900	112	609	301	224
100	118	480	10.5	292	11,850	73,500	54,000	40,300	118	735	540	403
120	132	390	12.2	314	13,950	91,200	76,300	59,000	116	760	636	492
140	141	355	13.1	331	15,400	102,700	90,300	70,500	110	734	645	504
160	146	345	13.6	346	16,350	109,900	98,900	76,900	102	687	618	481

EXCELLENT SITE—INDEX 70

20	16	2,800	1.7	47	470				24			
40	53	1,370	4.5	151	3,030	8,300	600	400	76	208	15	10
60	86	760	7.4	223	6,710	33,800	13,400	10,300	112	563	223	172
80	115	450	10.4	266	10,350	63,500	46,000	34,600	129	794	575	432
100	138	300	13.5	296	13,500	90,500	81,000	63,200	135	905	810	632
120	154	235	15.7	318	15,900	109,400	103,300	81,000	132	912	861	675
140	164	220	16.7	335	17,500	121,300	116,100	91,600	125	866	829	654
160	171	215	17.2	350	18,450	128,600	123,600	96,800	115	804	772	605

HEIGHT GROWTH AND SITE INDEX

Figure 2 portrays the trend of average dominant height over age. These curves are based on the growth of dominant western white pines only. On good sites (site index 60) white pine dominants average about 1 foot a year in height growth in stands between 40 and 140 years of age. The dotted lines in Figure 2 indicate the limits of each site-index group at any age between 20 and 160 years in terms of average dominant height.

The site indices used in the present study are merely more exact expressions of the following general descriptive terms not capable of exact definition:

	Site index
Very best or excellent (Site I)	80–70
Good (Site II)	60
Fair (Site III)	50
Poor (Site IV)	40
Very poor (Site V)	30

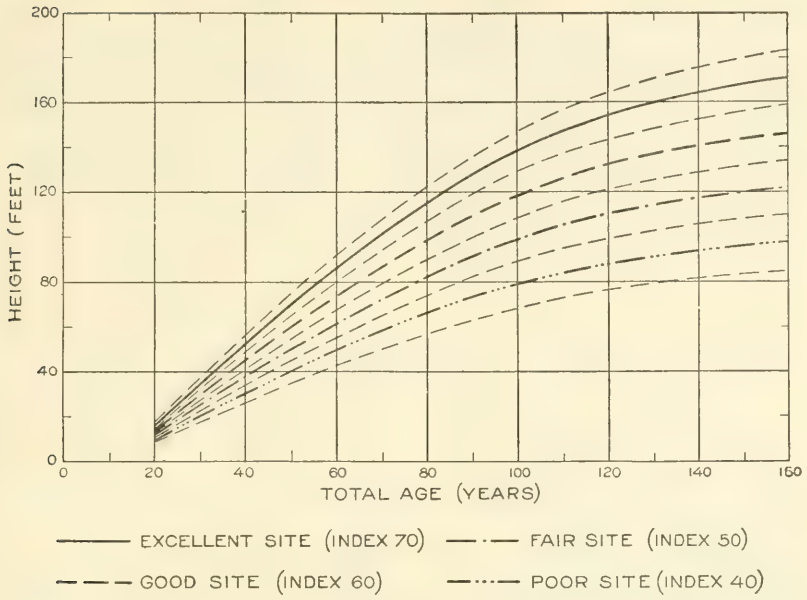

FIGURE 2.—Height curves for average dominant and codominant western white pine

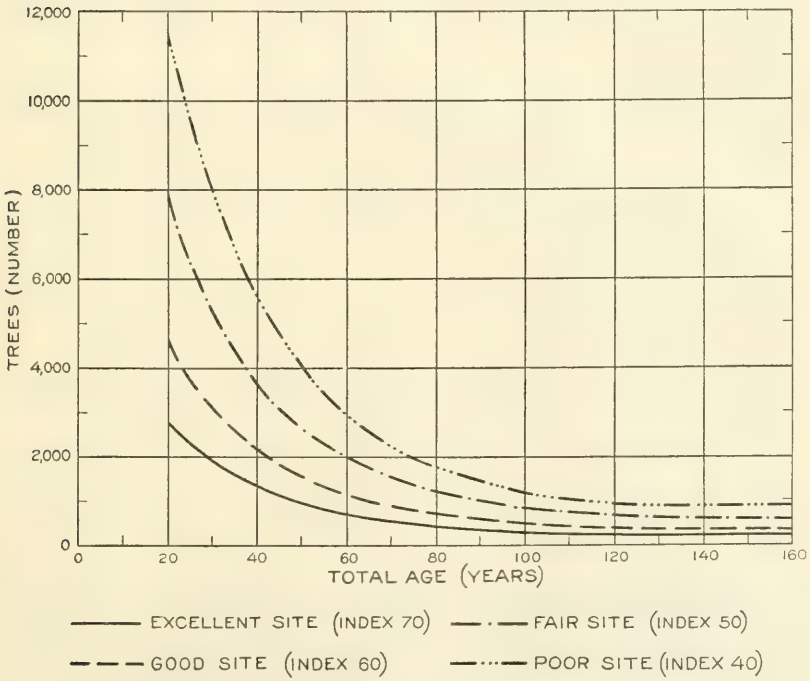

FIGURE 3.—Curves for total number of trees per acre 0.6 inch d. b. h. and larger

NUMBER AND SIZE OF TREES

Figure 3 depicts the total number of trees 0.6 inch d. b. h. and larger. The extremely rapid decrease in number of trees with increasing age is strikingly apparent. On good sites (site index 60) the total number of trees per acre drops from 4,700 at 20 years to 720 at 80 years, and to 390 at 120 years. The number of trees also decreases rapidly with increase in site index. On poor soils (site index 40)

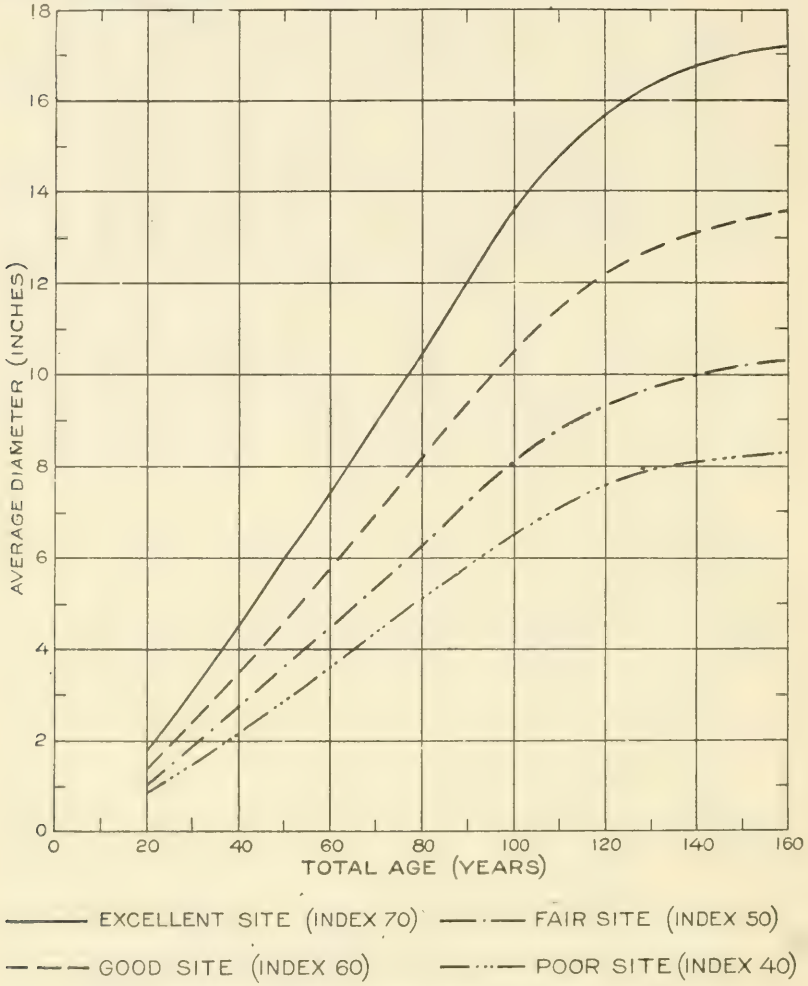

FIGURE 4.—Curves for diameter breast high of average tree

white pine stands average about 980 stems per acre at 120 years, and on excellent soils (site index 70) about 235 stems at the same age. The occurrence of more trees per acre on poor sites than on good sites in natural stands beyond the seedling stage is typical of all forest types so far investigated both here and abroad. The number of tree values given in the tables, however, must be considered little better than approximations, as the total number of trees per acre is extremely

variable in western white pine stands. Occasionally the usual tendency is reversed, and individual stands on good sites contain more trees than stands of the same age on poor sites, and commonly the number of trees on individual plots differs greatly from the average values given in the table.

The size of the tree of average basal area for various age-site conditions is shown in Figure 4. In general, the trees in fully stocked western white pine stands run very small. On good sites at 120 years, for example, the average tree is only 12.2 inches d. b. h. At this age on good sites some 27 per cent of the trees are still under 7 inches d. b. h. and about 60 per cent still under 13 inches d. b. h.

CUBIC-FOOT VOLUMES

Figure 5 portrays the total wood produced, including stump and tip, but not bark, in all trees 0.6 inch d. b. h. and larger. Density

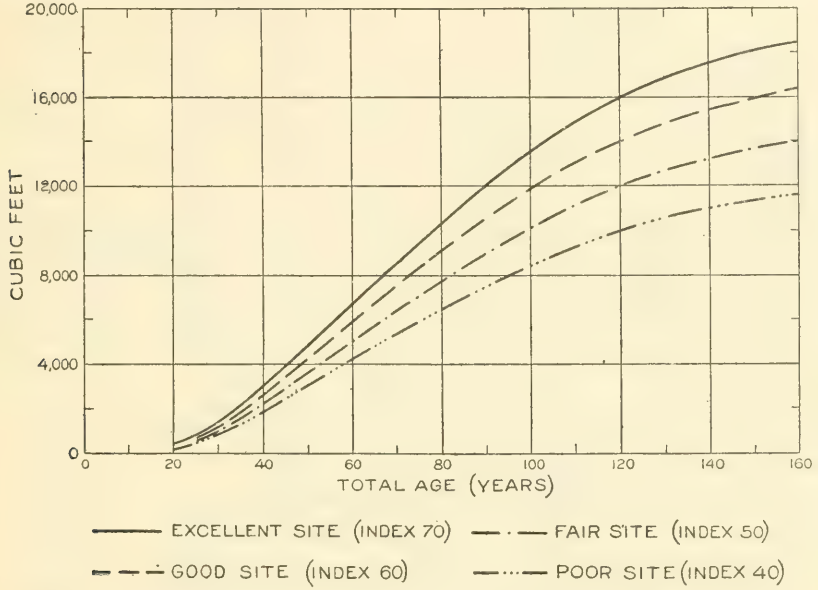

FIGURE 5.—Curves for total cubic-foot volume per acre, excluding bark

of stand and rapidity of growth both contribute to produce high cubic-foot volumes. The average fully stocked stand on site index 60 produces close to 14,000 cubic feet of wood at 120 years.

BOARD-FOOT VOLUMES

TREES IN AND ABOVE THE 7-INCH-DIAMETER CLASS

Figure 6 shows the total board-foot contents produced in fully stocked stands. These yield values include the volume of every tree 6.6 inches d. b. h. or larger that will furnish at least one 16-foot log with a 5-inch top diameter. The international (⅛-inch) rule according to which the yields are estimated is the most satisfactory log rule for estimating the board-foot content obtainable by complete utilization and with good sawing practice. The timber-producing capac-

ity of western white pine stands is strikingly apparent in the total board-foot tables, the average fully stocked stand producing about 90,000 board feet (international rule) at 120 years on good sites. Yields of this character are not obtainable, of course, over large areas in natural stands in which yields are reduced by blank spaces and irregularities in the stand, defect, and lack of complete utilization to the limits shown in the tables. Natural openings, resulting from lack of seed, snow breakage, insect attack, and similar phenomena, all reduce yields. In addition, the tables are constructed to show gross yields; i. e., the content of every tree above a given

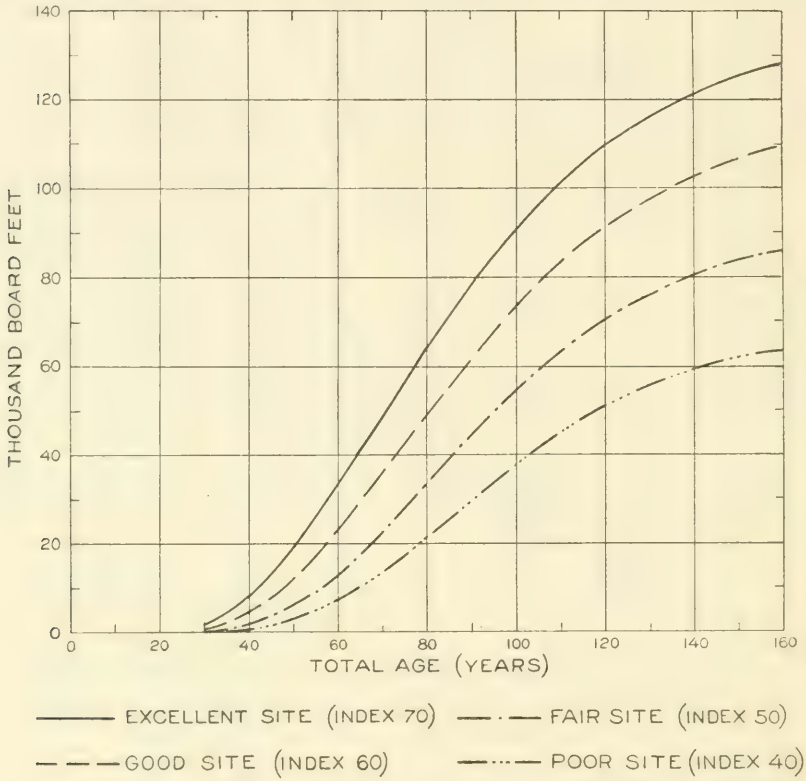

FIGURE 6.—Curves for total board-foot volume per acre, international rule (⅛-inch saw kerf), trees 6.6 inches d. b. h. and larger

diameter limit regardless of species and defect. Under present logging practices, however, a considerable amount of material is invariably left in the woods in the form of small trees and trees that are defective or unmerchantable on account of their low market value. These factors must all be considered when comparing the total yields shown in Figure 6 with present stands and the cut from areas now being logged. Extensive cruises indicate that well-stocked western white pine stands, exclusive of the larger nonstocked areas such as natural meadows and nonreproducing burns, average about 70 per cent by basal area of the values listed in the yield tables (according to unpublished data compiled by C. R. Watson and Donald Bruce,

1928). On several national-forest timber-sale areas approximately such volumes have been cut.[3]

TREES IN AND ABOVE THE 13-INCH-DIAMETER CLASS

Figure 7 depicts the board-foot yields by the international (⅛-inch) rule in all trees 12.6 inches d. b. h. and larger. Fully stocked stands on good sites at 120 years contain about 76,300 board feet per acre in trees 12.6 inches d. b. h. and larger, scaled to a 5-inch top diameter. Note in Table 1 the material differences between the international and Scribner values for trees 13 inches and up. These discrepancies

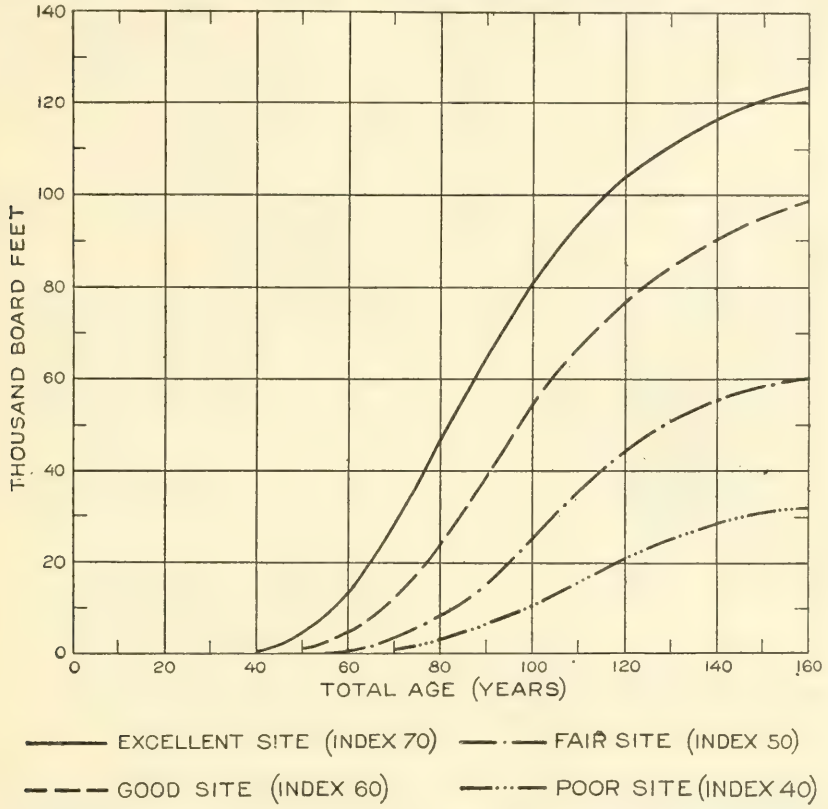

FIGURE 7.—Curves for board-foot volume per acre, international rule (⅛-inch saw kerf), trees 12.6 inches d. b. h. and larger

are principally due to the log rule. If computations for overrun are omitted, the international rule shows much more accurately than the Scribner rule the actual board-foot contents that can be cut out under efficient sawmill practice (*5*). The international rule used here assumes the use of saws cutting a ⅛-inch kerf. If a ¼-inch kerf is cut, the yields should be reduced 9.5 per cent.

[3] For example, Scott Creek on the Coeur d'Alene National Forest, averaged 39,600 board feet per acre by actual log scale, Scribner rule. This cut was in 90 to 100 year old timber from a drainage area of 790 acres. The stand, therefore, actually cut about 74 per cent of normal 100-year volume for good site (site index 60). (Table 13.) If unmerchantable and uncut material left in the woods is included, this stand ran 75 to 85 per cent of normal over more than a section.

INCREMENT AND ROTATION AGE

Figures 8, 9, and 10 show the rate of growth in western white pine stands in terms of periodic and mean annual increment. Figure 8 portrays growth in cubic feet and Figures 9 and 10 growth in board feet in trees 6.6 inches and 12.6 inches in diameter or more, respectively. The periodic-increment curves show the average rate of growth by 10-year periods, the peak of the curve in each instance indicating the decade of most rapid growth. This peak occurs between the ages of 50 and 120 years, varying with the kind of product and the site conditions. The peak or culmination of mean annual growth does not come until considerably later. This peak also is influenced by site and kind of product, and occurs on good sites (index 60) at 105 years for total wood production in cubic feet, at

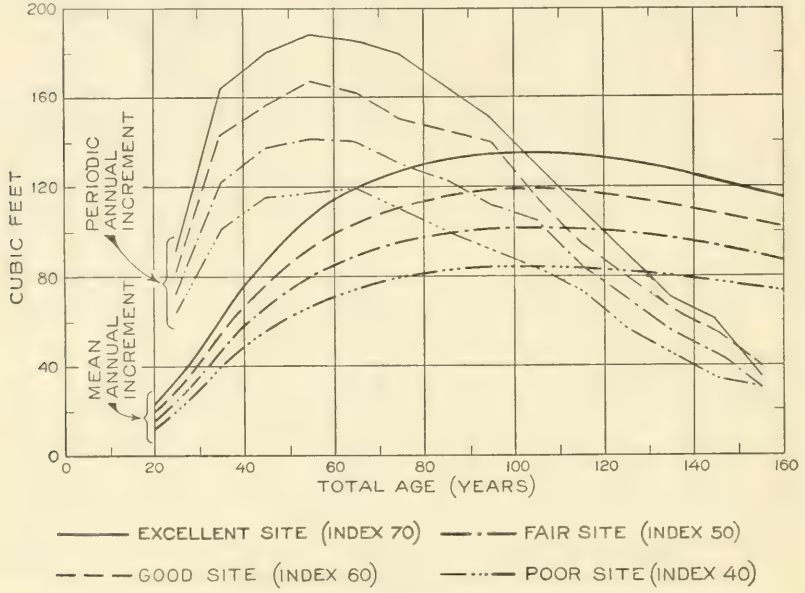

FIGURE 8.—Curves for periodic and mean annual increment in cubic feet, trees 0.6 inch d. h. b. and larger

115 years for total wood production in board feet (international rule) for trees 6.6 inches d. b. h. and larger, and at 135 years for board-foot volumes (international rule) for trees 12.6 inches and up. Growth in total board-foot volumes culminates at 110 years on excellent soils and at 130 years on poor soils. This point of culmination, or period at which maximum mean annual growth occurs, is usually spoken of as the rotation age. A stand cut at this time will yield the maximum volume return per year of growth.

Rate of growth, of course, is only one of a number of factors to be considered in fixing the proper age at which to cut a given stand. The type of product desired, the run of lumber grades, the financial aspects of prolonged holding, and the silvicultural features of the forest must all be considered in deciding upon the age at which to cut. Nevertheless, volume production alone is an important item to

consider in western white pine stands, in which on most sites the board-foot contents are nearly doubled or more than doubled between 80 and 120 years.

PREDICTING THE YIELDS OF SECOND-GROWTH STANDS

To use the normal tables in predicting future yields of natural second-growth western white pine stands, it is first necessary to determine the age, site quality, and degree of stocking of the stands

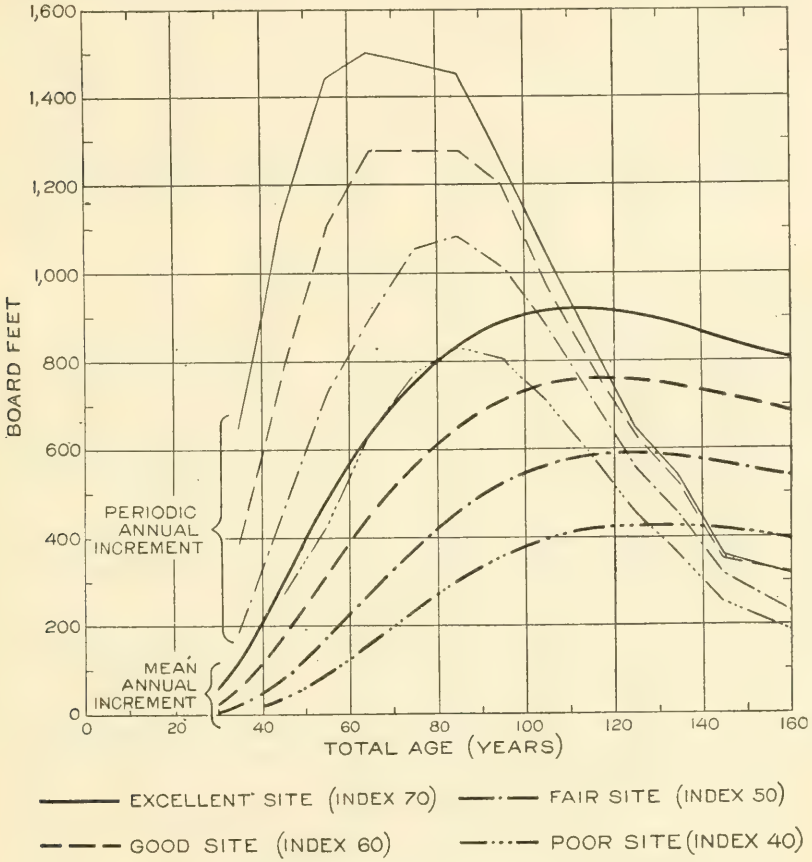

FIGURE 9.—Curves for periodic and mean annual increment in board feet, international rule, trees 6.6 inches d. h. b. and larger

for which such forecasts are to be made. These factors can be determined with relative ease on small tracts by measuring one or more selected sample areas. But for good-sized tracts this task will usually require a strip or line plot survey to locate and map age-class divisions, nontimbered areas, and distinct differences in stand density and site conditions. The general procedure in this work is practically the same as in a timber cruise, and the same factors determine the degree of intensity with which the survey is conducted. Site mapping introduces a new element, but as the range of sites in the

western white pine type is relatively small, the division of a tract into two or at most three site classes should be sufficient for all practical purposes.

AGE DETERMINATION

The first step in the application of yield tables is to tally on each sample strip or plot the total number of trees in each diameter class

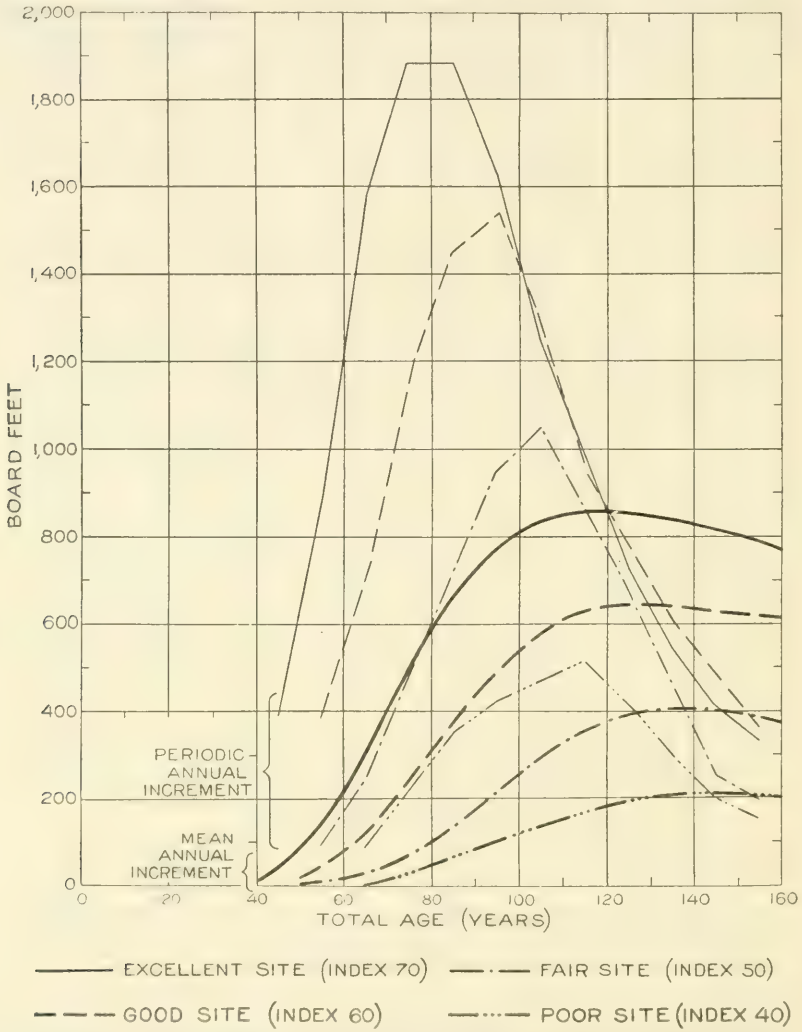

FIGURE 10.—Curves for periodic and mean annual increment in board feet, international rule. trees 12.6 inches d. b. h. and larger

1 inch and up for later use in computing stand density. In conjunction with this work, age determinations should be made on each sample plot or at frequent intervals along the strip line by counting the growth rings of several dominant white pines, either on the stump or on a core to the pith extracted with an increment borer. These

ring counts should be taken 1 foot above the average ground level or the count adjusted by adding in the number of whorls between the point of count and the 1-foot level. (The whorls or successive points along the trunk at which branches have originated are usually distinguishable on white pine trees by the knots even when the branches are entirely gone.) Add 5 years to this count on average soils, 4 years on better-than-average soils, and 6 years on poorer-than-average soils. This is the period required by dominant seedlings to grow 1 foot in height. The age of the oldest tree determined in this manner is taken as the age of the stand, provided the age of this tree does not differ by more than three years from that of the next oldest tree. This latter precaution is to avoid taking the age of veterans or relics of a former, older stand, individuals of which may have escaped the fire or other cause by which the present stand was established. Check the age by additional borings at any point where a change in age class appears to have taken place. Occasionally an intermediate or suppressed tree should be bored to see if the stand is essentially even-aged; i. e., all trees within about a 20-year range.

SITE DETERMINATION

Site determinations should also be made in conjunction with the strip or line-plot survey. This is done by measuring at fairly frequent intervals the heights of 15 to 20 dominant (dominant and codominant) white pines growing in a fairly dense portion of the stand. These heights should be measured with a Forest Service Abney level or some instrument of equal accuracy, and the distance should be taped, not paced. Extreme care must be taken to measure dominant trees of all sizes from those barely codominant up to and including the tallest trees in the stand and to distribute the measurements well over the range between these limits. Care should be taken also to exclude any surviving veterans of an older-age class. Then, for each group of trees measured, average the heights taken, refer either to Figure 2 or to the site-classification chart, Figure 11, and convert average dominant height to site index. This is done with Figure 11 by passing a straight line through the age of the stand on scale A and the average height just computed (the average height of the dominant and codominant trees) on scale B. Read the site index where this line crosses scale C. In the example illustrated, a 30-year-old stand in which the dominants averaged 20 feet in height, the site quality is classified as poor (site index 40).

DETERMINATION OF STOCKING

From the cruise data in hand, map out the major age-site divisions and compute for each the average age, site, and basal area, the latter being readily calculated from the stand tally of trees by diameter class. Then for each major area divide the computed average basal area by the yield-table basal area for the same age and site index, expressing the result as a percentage. The tabular yields at any future age for the same site index multiplied by this percentage will give the yields to be expected at that age.

For example: Given a stand 80 years of age with an average basal area per acre of 184 square feet and a site index of 60 feet; to predict

the yields in basal area, cubic volume, and board-foot volume when this stand reaches 120 years, or rotation age:

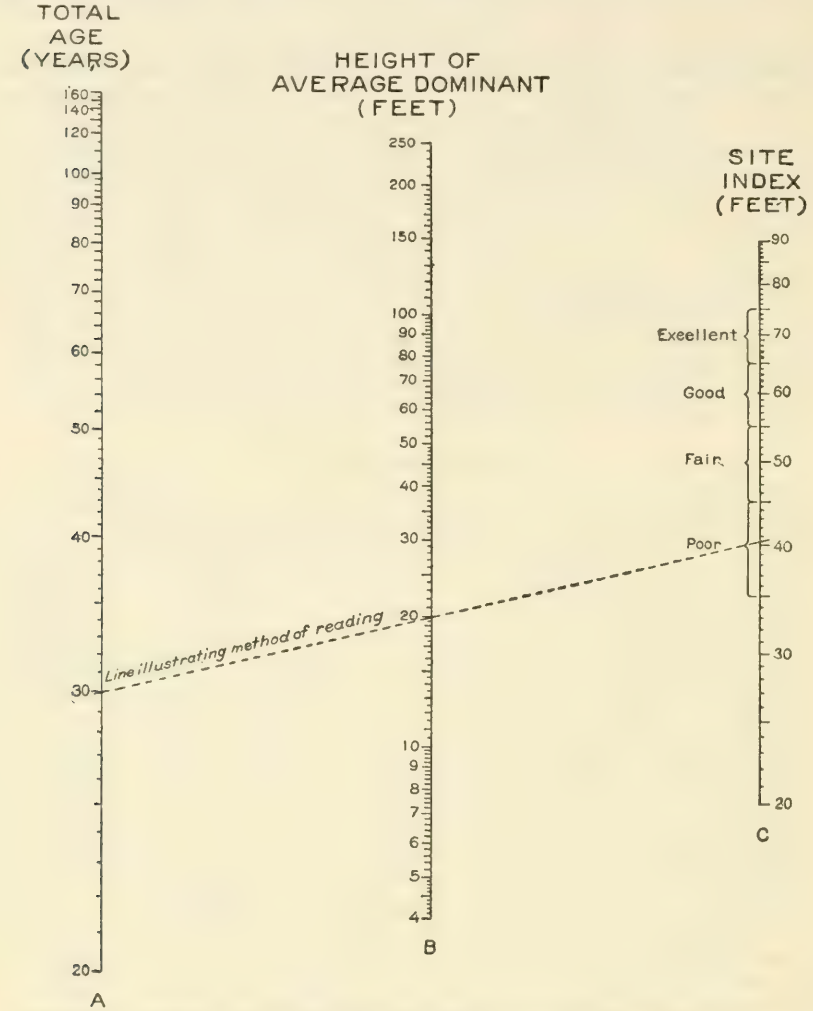

FIGURE 11.—Alinement chart for determining site index from age of stand and height of average dominant white pine

At 80 years, site index 60:

Actual basal area	=184 square feet.
Yield-table basal area	=263 square feet.
Percentage of stocking	= 70 per cent.

Yield-table values at 120 years (international rule—6.6 inches d. b. h. and larger):

Basal area	= 314 square feet.
Cubic volume	=13,950 cubic feet.
Total board-foot volume	=91,200 board feet.

These values reduced for 70 per cent stocking are:

Basal area	= 220 square feet.
Cubic volume	= 9,657 cubic feet.
Total board-foot volume	=63,840 board feet.

A conservative operator would reduce these predicted yields by at least 10 per cent more to allow for breakage in logging and defect.

OTHER FEATURES OF APPLICATION

The method of application here suggested is the conventional one of applying normal-yield tables. It has been tried on a fairly large scale in the Douglas fir region and found workable and satisfactory as far as the field work is concerned. It is based on the assumption that the present relationship between actual and tabular yields will be the same at any period in the future within the tabular limits. This assumption is, of course, subject to some error. For example, there is considerable evidence that understocked stands tend to approach or equal tabular yields with increase in age. Changes in this relationship might also be brought about through the influence of stand composition, through a material increase in the amount of defect, through the influence of climate, particularly of wet and dry cycles, or through further losses caused by snow breakage, insects, or disease. Nevertheless, the method suggested is the best now available and should prove entirely satisfactory under our present economic conditions and rough methods of management.

When board-foot-volume predictions only are desired and the stand is sufficiently advanced in years to contain a reasonable number of trees of merchantable size, a somewhat simplified procedure may be adopted. Age and site class must be determined as before. But degree of stocking can be computed by simply counting on representative areas the total number of trees above the chosen diameter limit; for example, the number of trees in and above the 7 inch or 13 inch diameter class. This number should be expressed as a percentage of the tabular number above such limits for the same age-site condition. Then the tabular figures for board-foot yields above similar diameter limits multiplied by this percentage figure will give the predicted board-foot yields. This method is recommended for short-time predictions only. Where applicable, it is probably more accurate than the conventional method.

The Forest Service is now conducting several studies in an attempt to check and improve the application of normal-yield tables (*11*). If, as is expected, one of these studies should be undertaken in the western white pine type, it may make possible a better definition of the board foot-basal area relationship and of other improvements in application technic.

DISCUSSION OF STAND TABLES

Stand tables ordinarily show numbers of trees per acre arranged by diameter classes. They may also be made to show the percentage of total number of trees per acre, or the percentage of the total volume per acre found in each diameter class or above any diameter limit. Tables 25 to 34 give the proportion of number of trees, basal area, cubic and board foot volume occurring above various diameter limits in fully stocked western white pine stands.

125913°—32——2

APPLICATION OF STAND TABLES

To apply these tables it is necessary to know only the average diameter of the stand and the total number of trees, basal area, or volume per stand or unit of area. For example, the yield tables show that 120-year-old fully stocked stands on good sites contain on an average 390 trees, with an average diameter of 12.2 inches breast high. The stand tables, properly interpolated for an average diameter of 12.2 inches, furnish the percentage of total number of trees above various diameter limits. Then a series of readings at successive diameter limits, each reading subtracted in turn from the preceding tabular value, give the percentage of trees in each individual diameter class. These percentage values are easily converted into actual number of trees by multiplying by the total number of trees in the stand, in this case 390. Table 2 was derived in this way. The number of trees in any single diameter class or above any given diameter limit can be computed in this manner for any stand for which the average diameter and total number of trees are known. Basal area and cubic and board foot values can be obtained in similar fashion.

TABLE 2.—*Sample computation of stand table, showing the distribution of trees in a fully stocked 120-year-old stand on good site (site index 60)*

Diameter breast high (inches)	Distribution of trees by diameter class		Diameter breast high (inches)	Distribution of trees by diameter class	
	Per cent	*Number*		*Per cent*	*Number*
1–4	18	70	17–20	13	51
5–8	21	82	21–24+	5	19
9–12	21	82			
13–16	22	86	Total	100	390

The stand tables, therefore, make an excellent supplement to the yield tables proper, for they add to the yield-table figures on total number of trees or volumes per acre, additional information on the number of trees of different sizes, and the volume above various diameter limits. These figures are obviously of considerable interest and value to any operator or forest manager who is contemplating diameter-limit cuttings, or who wishes to know about how many trees or what percentage of the total volume will be available for various products, depending somewhat on size; for example, ties, pulpwood, or saw timber.

EFFECT OF STOCKING AND COMPOSITION

The stand tables are directly applicable only to fully stocked stands of average composition. They should, however, furnish satisfactory approximations of the distribution of trees and volumes in stands approaching full stocking, a condition fairly common in the western white pine type, in which well-stocked stands exclusive of large openings average, as has been said, about 70 per cent of normal.

Composition, of course, also affects tree distribution, tolerant species tending to concentrate in the smaller diameter classes and intolerant ones in the larger. The general tendency, therefore, is to underestimate the number of small trees and overestimate the number of large trees in stands running heavily to cedar and hemlock. These errors due to composition are not very serious, and may be eliminated

entirely for number of tree values by the use of tables showing the distribution by diameter of trees of individual species. Tables 26 to 31, inclusive, show the distribution of the number of trees for the six most common species in the western white pine type. To use these tables it is necessary to know only the average diameter of the stand, all species included, and the number of trees of each species per unit of area. Then, dealing with each species separately, the percentage of trees in each diameter class is computed as before. The percentages for each species are then multiplied by the total number of trees of that particular species per unit of area, and the number of trees of each species in the various diameter classes derived in this way. The values for each diameter class are then added to obtain the total number of trees in each class for this particular stand composition.

DISCUSSION OF VOLUME TABLES

Volume tables show the contents of trees of various sizes in terms of some standard unit, such as cubic or board feet. Tables 35 to 64 give the volumes of the six most important species occurring in the western white pine type, namely, western white pine, western larch, western red cedar, Douglas fir, lowland white fir, and western hemlock. Tables are given in both cubic and board feet, the latter in both the international (¼-inch) and Scribner rules to both total and merchantable height.

These volume tables list correct values only for trees of the species named occurring in western white pine stands under 160 years of age. Within these limits, however, they are usable throughout the entire western white pine region, regardless of general locality or site conditions, for a careful mathematical analysis indicates that these factors have little effect on tree form in second-growth stands and hence on tree volume when the variables of diameter and height are eliminated. Some adjustment may be necessary in local use, however, and the procedure to be followed in checking and adjusting the tables is explained in detail in the volume-table section of the appendix.

YIELD TABLES

TOTAL STAND

TABLE 3.—*Number of trees per acre 0.6 inch d. b. h. and larger*

Total age (years)	Number of trees, by site index—						Total age (years)	Number of trees, by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20	15,800	11,500	7,800	4,700	2,800	2,050	100	1,700	1,220	820	480	300	215
30	10,950	8,050	5,220	3,180	1,940	1,420	110	1,480	1,060	720	420	260	185
40	7,750	5,600	3,650	2,210	1,370	1,000	120	1,350	980	660	390	235	170
50	5,600	4,070	2,680	1,590	1,000	710	130	1,290	930	630	370	225	165
60	4,150	3,020	2,000	1,190	760	540	140	1,250	910	610	355	220	160
70	3,180	2,300	1,550	930	580	410	150	1,220	900	600	350	215	155
80	2,500	1,830	1,230	720	450	320	160	1,210	890	590	345	215	155
90	2,030	1,460	990	580	360	260							

TABLE 4.—*Size of average tree, based on diameter breast high of tree of average basal area*

Total age (years)	Average diameter breast high (inches), by site index—						Total age (years)	Average diameter breast high (inches), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20	0.7	0.8	1.0	1.3	1.7	2.0	100	5.5	6.5	8.0	10.5	13.5	16.0
30	1.3	1.5	1.9	2.4	3.1	3.7	110	6.0	7.1	8.8	11.5	14.7	17.5
40	1.8	2.2	2.7	3.5	4.5	5.3	120	6.4	7.6	9.3	12.2	15.7	18.6
50	2.4	2.9	3.6	4.7	5.9	7.1	130	6.7	7.9	9.7	12.7	16.3	19.3
60	3.1	3.6	4.5	5.8	7.4	8.8	140	6.8	8.1	10.0	13.1	16.7	19.9
70	3.7	4.3	5.3	7.0	8.9	10.6	150	7.0	8.2	10.2	13.4	17.0	20.3
80	4.3	5.1	6.2	8.2	10.4	12.4	160	7.1	8.3	10.3	13.6	17.2	20.5
90	4.9	5.8	7.1	9.4	12.0	14.2							

TABLE 5.—*Basal area per acre in trees 0.6 inch d. b. h. and larger*

Total age (years)	Basal area (square feet), by site index—						Total age (years)	Basal area (square feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20	44	45	46	46	47	47	100	282	286	289	292	296	300
30	99	100	101	102	104	105	110	293	296	300	304	308	311
40	144	146	148	149	151	153	120	302	306	310	314	318	322
50	182	184	186	189	191	194	130	311	315	319	323	327	331
60	212	215	218	221	223	226	140	319	323	327	331	335	340
70	235	238	241	244	247	250	150	326	331	335	339	343	348
80	253	257	260	263	266	270	160	333	338	342	346	350	354
90	269	272	275	279	282	286							

TABLE 6.—*Total cubic-foot volume per acre, including stump and tip but not bark for all trees 0.6 inch d. b. h. and larger*

Total age (years)	Volume (cubic feet), by site index—						Total age (years)	Volume (cubic feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20	170	240	320	400	470	540	100	6,720	8,420	10,100	11,850	13,500	15,400
30	700	880	1,050	1,220	1,390	1,570	110	7,350	9,250	11,150	13,000	14,800	16,850
40	1,500	1,890	2,270	2,650	3,030	3,400	120	7,890	9,980	12,000	13,950	15,900	18,100
50	2,400	3,040	3,640	4,210	4,830	5,470	130	8,360	10,550	12,700	14,750	16,800	19,100
60	3,370	4,210	5,050	5,880	6,710	7,600	140	8,740	11,000	13,250	15,400	17,500	19,900
70	4,280	5,400	6,450	7,500	8,560	9,730	150	9,010	11,350	13,700	15,950	18,100	20,550
80	5,160	6,500	7,750	9,000	10,350	11,750	160	9,200	11,650	14,000	16,350	18,450	21,000
90	5,980	7,500	8,980	10,450	12,000	13,650							

TABLE 7.—*Mean annual cubic-foot increment per acre in trees 0.6 inch d. b. h. and larger*

Total age (years)	Increment (cubic feet), by site index—						Total age (years)	Increment (cubic feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20	8	12	16	20	24	27	100	67	84	101	118	135	154
30	23	29	35	41	46	52	110	67	84	101	118	135	153
40	38	47	57	66	76	85	120	66	83	100	116	132	151
50	48	61	73	84	97	109	130	64	81	98	113	129	147
60	56	70	84	98	112	127	140	62	79	95	110	125	142
70	61	77	92	107	122	139	150	60	76	91	106	121	137
80	64	81	97	112	129	147	160	58	73	88	102	115	131
90	66	83	100	116	133	152							

TREES 6.6 INCHES D. B. H. AND LARGER

TABLE 8.—*Number of trees per acre 6.6 inches d. b. h. and larger*

Total age (years)	Number of trees, by site index—						Total age (years)	Number of trees, by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20						5	100	425	440	420	330	240	185
30					30	70	100	455	450	405	310	220	170
40			25	65	130	200	220	470	455	400	295	205	160
50		50	105	170	255	295	295	480	460	395	285	200	155
60		140	200	275	340	335	305	490	465	390	280	195	(1)
70		230	295	355	370	330	280	495	470	390	280	195	(1)
80		310	370	405	370	305	245	500	475	390	275	195	(1)
90		380	420	420	360	270	215						

[1] No data.

TABLE 9.—*Average diameter of trees per acre, 6.6 inches d. b. h. and larger*

Total age (years)	Average diameter breast high (inches), by site index—						Total age (years)	Average diameter breast high (inches), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20						7.4	100	9.0	9.6	10.5	12.4	14.9	17.1
30				7.5	7.8	8.1	110	9.3	9.9	11.1	13.2	16.0	18.4
40		7.5	7.7	8.0	8.5	8.9	120	9.5	10.2	11.5	13.8	16.8	19.3
50	7.5	7.7	8.0	8.6	9.2	9.9	130	9.7	10.4	11.8	14.2	17.3	19.8
60	7.8	8.0	8.5	9.2	10.1	11.1	140	9.8	10.6	12.0	14.5	17.7	(1)
70	8.1	8.4	8.9	9.9	11.1	12.5	150	9.9	10.7	12.2	14.8	18.0	(1)
80	8.4	8.8	9.4	10.7	12.3	14.0	160	9.9	10.8	12.3	15.0	18.1	(1)
90	8.7	9.2	9.9	11.5	13.6	15.5							

[1] No data.

TABLE 10.—*Basal area per acre in trees 6.6 inches d. b. h. and larger*

Total age (years)	Basal area (square feet), by site index—						Total age (years)	Basal area (square feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20						1	100	189	221	251	277	290	298
30				9	23	35	110	214	241	271	293	304	312
40		8	21	45	79	94	120	231	258	286	305	315	323
50	15	33	60	103	137	157	130	245	271	298	315	326	333
60	47	69	108	157	187	205	140	255	283	307	324	335	(1)
70	83	113	154	199	223	238	150	264	293	316	332	343	(1)
80	120	157	194	232	252	261	160	271	302	323	339	349	(1)
90	158	194	225	258	273	281							

[1] No data.

TABLE 11.—*Total board-foot volume per acre in trees 6.6 inches d. b. h. and larger, international rule, ⅛-inch saw kerf*

Total age (years)	Volume (board feet), by site index—						Total age (years)	Volume (board feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20						100	100	24,700	38,000	54,300	73,500	90,500	106,100
30				600	1,700	2,900	110	30,200	45,100	63,100	83,200	100,900	117,300
40		500	1,900	4,400	8,300	12,000	120	34,800	51,000	70,300	91,200	109,400	126,500
50	1,300	3,200	6,500	12,300	19,500	26,200	130	38,400	55,600	75,900	97,500	115,900	133,700
60	3,900	7,500	13,700	23,300	33,800	43,000	140	41,000	59,200	80,400	102,700	121,300	(1)
70	8,000	13,900	22,800	36,000	48,800	60,700	150	43,100	61,700	83,600	106,700	125,400	(1)
80	13,100	21,600	33,300	48,700	63,500	77,200	160	44,700	63,600	85,900	109,900	128,600	(1)
90	18,800	29,900	44,100	61,500	78,000	92,800							

[1] No data.

TABLE 12.—*Mean annual board-foot increment per acre in trees 6.6 inches d. b. h. and larger, international rule, ⅛-inch saw kerf*

Total age (years)	Increment (board feet), by site index—						Total age (years)	Increment (board feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20						5	100	247	380	543	735	905	1,061
30				20	57	97	110	275	410	574	756	917	1,066
40		12	48	110	208	300	120	290	425	586	760	912	1,054
50	26	64	130	246	390	524	130	295	428	584	750	892	1,028
60	65	125	228	388	563	717	140	293	423	574	734	866	(1)
70	114	199	326	514	697	867	150	287	411	557	711	836	(1)
80	164	270	416	609	794	965	160	279	398	537	687	804	(1)
90	209	332	490	683	867	1,031							

[1] No data.

TREES 7.6 INCHES D. B. H. AND LARGER

TABLE 13.—*Board-foot volume per acre in trees 7.6 inches d. b. h. and larger, Scribner rule*

Total age (years)	Volume (board feet), by site index—						Total age (years)	Volume (board feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20							100	13,600	22,600	36,300	53,500	68,500	82,500
30				150	450	1,200	110	17,500	28,300	43,600	62,100	77,500	92,000
40		50	400	1,700	3,900	6,200	120	20,800	33,100	49,500	68,700	84,700	99,400
50	250	900	2,500	6,000	11,100	16,400	130	23,300	36,700	54,100	73,700	90,500	105,800
60	1,100	2,900	6,600	13,100	21,700	29,700	140	25,400	39,400	57,900	77,600	95,100	(1)
70	3,200	6,500	12,300	22,500	33,800	44,300	150	27,000	41,500	60,600	80,900	98,500	(1)
80	6,000	11,300	19,500	32,800	46,500	58,200	160	28,200	43,200	62,300	83,700	100,500	(1)
90	9,600	16,800	27,900	43,300	58,300	71,300							

[1] No data.

TABLE 14.—*Mean annual increment in trees 7.6 inches d. b. h. and larger, Scribner rule*

Total age (years)	Increment (board feet), by site index—						Total age (years)	Increment (board feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20							100	136	226	363	535	685	825
30				5	15	40	110	159	257	396	565	705	836
40		1	10	42	98	155	120	173	276	412	572	706	828
50	5	18	50	120	222	328	130	179	282	416	567	696	814
60	18	48	110	218	362	495	140	181	281	414	554	679	(1)
70	46	93	176	321	483	633	150	180	277	404	539	657	(1)
80	75	141	244	410	581	728	160	176	270	389	523	628	(1)
90	107	187	310	481	648	792							

[1] No data.

TREES 12.6 INCHES D. B. H. AND LARGER

TABLE 15.—*Number of trees per acre 12.6 inches d. b. h. and larger*

Total age (years)	Number of trees, by site index—						Total age (years)	Number of trees, by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
40[1]					4	8	110	31	57	101	143	147	131
50			1	4	17	38	120	40	71	116	153	147	126
60		1	5	19	49	78	130	48	82	128	159	147	(2)
70	1	5	14	44	86	110	140	56	90	138	164	148	(2)
80	5	13	31	76	115	132	150	60	97	144	167	148	(2)
90	12	24	54	106	134	139	160	64	102	147	171	149	(2)
100	22	41	80	128	145	137							

[1] No 12.6-inch trees below 40-year class. [2] No data.

TABLE 16.—*Average diameter of trees 12.6 inches d. b. h. and larger*

Total age (years)	Average diameter breast high (inches), by site index—						Total age (years)	Average diameter breast high (inches), by site index					
	30	40	50	60	70	80		30	40	50	60	70	80
40[1]					13.8	14.0	110	14.1	14.4	15.0	16.3	18.2	19.9
50			13.8	13.8	14.1	14.4	120	14.2	14.6	15.2	16.7	18.8	20.6
60		13.8	13.8	14.0	14.5	15.0	130	14.3	14.7	15.4	17.0	19.2	[2]
70	13.8	13.8	14.0	14.4	15.0	15.8	140	14.3	14.8	15.5	17.2	19.4	[2]
80	13.8	13.9	14.1	14.8	15.7	16.8	150	14.4	14.8	15.6	17.4	19.6	[2]
90	13.9	14.0	14.4	15.3	16.6	17.9	160	14.4	14.8	15.7	17.5	19.7	[2]
100	14.0	14.2	14.7	15.8	17.5	19.0							

[1] No 12.6-inch trees below 40-year class. [2] No data.

TABLE 17.—*Basal area per acre in trees 12.6 inches d. b. h. and larger*

Total age (years)	Basal area (square feet), by site index—						Total age (years)	Basal area (square feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
40[1]					4	9	110	34	65	124	207	266	283
50			1	4	19	43	120	44	83	146	232	283	292
60		1	5	20	56	96	130	54	97	166	251	296	[2]
70	1	5	15	50	105	150	140	62	108	181	265	304	[2]
80	5	14	34	91	154	203	150	68	116	191	276	310	[2]
90	13	26	61	135	202	243	160	72	122	198	286	315	[2]
100	24	45	91	175	242	270							

[1] No 12.6-inch trees below 40-year class. [2] No data.

TABLE 18.—*Board-foot volume per acre in trees 12.6 inches d. b. h. and larger, international rule (⅛-inch saw kerf)*

Total age (years)	Volume (board feet), by site index—						Total age (years)	Volume (board feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
40[1]					600	2,000	110	7,100	15,700	35,500	66,800	93,500	113,500
50			50	1,300	4,500	9,000	120	9,700	21,000	44,100	76,300	103,300	122,400
60		50	1,000	5,000	13,400	24,300	130	11,900	25,200	50,900	84,100	110,600	[2]
70	100	1,000	3,600	12,300	28,200	45,000	140	13,600	28,100	55,600	90,300	116,100	[2]
80	700	3,200	8,400	24,100	46,000	65,600	150	14,800	30,200	58,200	95,200	120,300	[2]
90	2,400	6,600	15,500	38,600	64,800	84,500	160	15,700	31,700	60,200	98,900	123,600	[2]
100	4,600	11,000	25,000	54,000	81,000	100,700							

[1] No 12.6-inch trees below 40-year class. [2] No data.

TABLE 19.—*Board-foot volume per acre in trees 12.6 inches d. b. h. and larger, Scribner rule*

Total age (years)	Volume (board feet), by site index—						Total age (years)	Volume (board feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
40[1]					400	1,400	110	5,400	12,400	26,100	50,800	73,400	88,600
50			50	800	3,300	7,000	120	7,600	16,000	32,200	59,000	81,000	96,000
60		50	700	3,700	10,300	17,800	130	9,500	18,800	37,000	65,200	87,000	[2]
70	100	600	2,800	9,700	21,200	34,000	140	10,900	21,000	41,000	70,500	91,600	[2]
80	500	2,300	6,500	17,900	34,600	50,500	150	11,700	22,700	43,800	74,400	94,800	[2]
90	1,600	4,800	12,100	28,700	50,300	65,500	160	12,500	24,300	45,500	76,900	96,800	[2]
100	3,300	8,300	19,200	40,300	63,200	79,100							

[1] No 12.6-inch trees below 40-year class. [2] No data.

TABLE 20.—*Mean annual board-foot increment per acre in trees 12.6 inches d. b. h. and larger, international rule (⅛-inch saw kerf)*

Total age (years)	Increment (board feet), by site index—						Total age (years)	Increment (board feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
30 [1]						2	100	46	110	250	540	810	1,007
40					15	50	110	65	143	323	607	850	1,032
50			1	26	90	180	120	81	175	368	636	861	1,020
60		1	17	83	223	405	130	92	194	392	647	851	(2)
70	1	14	51	176	403	643	140	97	201	397	645	829	(2)
80	9	40	105	301	575	820	150	99	201	388	635	802	(2)
90	27	73	172	429	720	939	160	98	198	376	618	772	(2)

[1] No 12.6-inch trees below 30-year class. [2] No data.

TABLE 21.—*Mean annual board-foot increment per acre in trees 12.6 inches d. b. h. and larger, Scribner rule*

Total age (years)	Increment (board feet), by site index—						Total age (years)	Increment (board feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
40 [1]					10	35	110	49	113	237	462	667	805
50			1	16	66	140	120	63	133	268	492	675	800
60		1	12	62	172	297	130	73	145	285	502	669	(2)
70	1	9	40	139	303	486	140	78	150	293	504	654	(2)
80	6	29	81	224	433	631	150	78	151	292	496	632	(2)
90	18	53	134	319	559	728	160	78	152	284	481	605	(2)
100	33	83	192	403	632	791							

[1] No 12.6-inch trees below 40-year class. [2] No data.

DOMINANT STAND

TABLE 22.—*Average diameter of dominant stand (dominant and codominant trees)*

Total age (years)	Average diameter breast high (inches), by site index—						Total age (years)	Average diameter breast high (inches), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20	1.0	1.2	1.5	2.1	2.9	3.4	100	8.9	10.2	12.1	14.8	17.6	19.8
30	2.1	2.5	3.1	4.1	5.2	6.2	110	9.6	11.0	13.0	15.8	18.7	21.0
40	3.1	3.7	4.6	5.9	7.4	8.6	120	10.1	11.6	13.6	16.5	19.5	(1)
50	4.1	4.9	6.0	7.7	9.4	11.0	130	10.5	12.0	14.0	17.0	20.1	(1)
60	5.2	6.0	7.4	9.3	11.3	13.0	140	10.7	12.2	14.3	17.3	20.4	(1)
70	6.2	7.1	8.6	10.8	13.1	14.9	150	10.8	12.3	14.5	17.5	20.7	(1)
80	7.1	8.3	9.9	12.3	14.7	16.7	160	11.0	12.4	14.6	17.7	20.8	(1)
90	8.1	9.3	11.0	13.6	16.3	18.3							

[1] No data.

TABLE 23.—*Cubic-foot volume per acre in dominant stand (dominant and codominant trees)*

Total age (years)	Volume (cubic feet), by site index—						Total age (years)	Volume (cubic feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20	100	150	200	250	300	350	100	4,850	6,200	7,700	9,400	11,400	13,650
30	450	550	700	850	950	1,100	110	5,350	6,900	8,600	10,550	12,800	15,350
40	1,000	1,250	1,500	1,800	2,100	2,450	120	5,800	7,500	9,350	11,500	14,000	16,750
50	1,600	2,050	2,500	3,000	3,500	4,050	130	6,150	8,000	9,950	12,300	14,950	(1)
60	2,300	2,900	3,550	4,250	5,050	5,850	140	6,450	8,350	10,450	12,950	15,700	(1)
70	2,950	3,800	4,650	5,550	6,600	7,750	150	6,700	8,650	10,850	13,450	16,300	(1)
80	3,600	4,650	5,650	6,850	8,250	9,700	160	6,850	8,900	11,150	13,850	16,700	(1)
90	4,250	5,450	6,700	8,150	9,850	11,650							

[1] No data.

TABLE 24.—*Height of average dominant (dominant and codominant) western white pine*

Total age (years)	Height (feet), by site index—						Total age (years)	Height (feet), by site index—					
	30	40	50	60	70	80		30	40	50	60	70	80
20	7	10	12	14	16	19	100	59	79	99	118	138	158
30	15	20	25	30	35	40	110	63	84	105	126	147	167
40	23	30	38	45	53	60	120	66	88	110	132	154	175
50	30	40	50	60	70	80	130	68	91	114	137	160	182
60	37	49	61	73	86	98	140	70	94	117	141	164	188
70	43	58	72	86	101	116	150	72	96	120	144	168	192
80	49	66	82	98	115	132	160	73	98	122	146	171	195
90	54	73	91	109	128	145							

STAND TABLES

TABLE 25.—*Percentage distribution of trees in and above successive diameter classes in stands of different average diameter; all species combined*

Diameter class (inches)	Distribution (per cent) by average stand diameter															
	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	13 inches	14 inches	15 inches	16 inches	17 inches	18 inches
1	100	100	100	100	100	100	100	100	100	100	100	100	100				
2	56	75	84	87	89	90	92	92	93	94	96	98	99				
3	8	42	62	72	77	81	83	85	87	89	92	95	98	99			
4		16	42	56	65	71	75	78	81	83	86	91	95	98			
5		4	24	42	53	61	67	71	75	78	81	86	91	96	99		
6			12	28	43	53	59	65	69	73	76	81	86	92	96	99	
7			5	18	33	44	52	58	63	67	71	76	82	87	93	96	99
8			2	10	23	35	44	51	57	62	66	71	77	82	88	93	96
9				5	15	26	36	44	50	56	60	66	71	77	83	87	92
10				2	9	19	28	37	44	50	55	61	66	72	77	82	87
11					5	13	22	31	38	44	50	55	61	66	72	77	82
12					3	9	16	24	32	39	44	50	56	61	67	72	76
13					2	5	11	19	26	33	38	44	50	55	61	66	70
14						3	8	14	20	27	33	39	44	49	55	60	64
15						2	5	10	16	22	27	33	38	44	49	54	58
16							2	6	12	17	22	27	33	37	43	47	51
17								4	8	13	17	22	26	31	36	41	45
18								2	5	9	13	17	21	25	30	34	38
19									4	6	10	13	16	20	24	28	31
20									2	5	7	10	12	15	19	22	25
21										3	5	7	9	11	14	17	19
22										2	3	5	6	8	10	13	15
23											2	3	4	6	7	9	11
24												2	3	4	5	6	8
25													2	2	3	4	5

TABLE 26.—*Percentage distribution of trees in and above successive diameter classes in stands of different average diameter; western white pine only*

Diameter class (inches)	Distribution (per cent) by average stand diameter															
	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	13 inches	14 inches	15 inches	16 inches	17 inches
1	100	100	100	100	100	100	100	100								
2	62	84	89	91	94	97	98	99								
3		51	72	81	86	90	94	96	98	99						
4		19	50	67	76	83	88	92	95	97	99					
5		4	29	50	65	74	80	86	90	93	96	98				
6			14	34	52	64	73	79	85	89	93	95	98	99		
7			6	22	39	52	64	72	78	83	88	92	94	96	99	
8			2	12	29	42	54	64	71	77	83	87	90	93	96	98
9				6	19	32	44	55	64	71	77	82	86	89	93	95
10				3	12	23	34	46	54	64	71	76	81	85	89	92
11				1	7	16	26	37	46	55	64	70	75	79	84	88
12					4	11	20	29	38	47	56	64	69	74	79	83
13					2	7	14	23	31	40	49	57	63	68	74	78
14					1	4	10	17	24	33	41	49	56	62	68	73
15						3	6	12	19	26	34	42	48	54	62	67
16						1	4	9	14	21	28	35	41	47	54	60
17							3	6	10	16	22	29	34	40	47	53
18							1	4	7	11	17	23	28	33	39	46
19								2	4	8	12	18	22	27	32	38
20									3	5	9	13	17	21	26	32
21									2	3	6	9	12	16	20	25
22									1	2	4	6	8	11	14	19
23										1	2	4	5	7	10	13
24											1	2	3	5	7	9
25												1	2	3	4	6

TABLE 27.—*Percentage distribution of trees in and above successive diameter classes in stands of different average diameter; western larch only*

Diameter class (inches)	Distribution (per cent) by average stand diameter															
	1 inch	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	13 inches	14 inches	15 inches	16 inches	17 inches
1	100	100	100	100	100												
2	74	82	88	92	97												
3	15	49	68	79	90	99											
4	1	20	44	63	79	92	99										
5		5	25	45	65	83	93										
6		1	12	31	51	72	86	95									
7			4	19	38	59	76	87	95	99							
8			2	11	28	47	65	78	88	94	98						
9				5	18	36	52	68	79	87	93	97					
10				3	11	26	41	56	68	78	85	91	95	99			
11				1	6	18	32	45	58	68	77	83	89	93	96	98	
12					4	12	23	35	46	57	66	74	80	85	90	93	96
13					2	7	16	26	37	46	56	64	70	77	82	86	90
14					1	4	10	19	28	37	45	53	60	67	73	78	82
15						3	7	13	21	29	36	43	50	58	63	69	74
16						2	4	9	15	22	28	35	40	47	53	59	64
17						1	3	5	10	15	21	27	32	38	43	49	54
18							2	3	6	10	15	20	25	31	35	39	44
19							1	2	4	7	10	14	18	23	27	31	36
20								1	3	4	7	10	13	17	21	25	29
21									2	3	4	7	9	12	15	18	22
22									1	2	3	4	6	8	10	13	16
23										1	2	3	4	5	7	9	11
24											1	2	3	4	5	6	8
25												1	2	2	3	4	5

TABLE 28.—*Percentage distribution of trees in and above successive diameter classes in stands of different average diameter; western hemlock only*

Diameter class (inches)	Distribution (per cent) by average stand diameter																
	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	13 inches	14 inches	15 inches	16 inches	17 inches	18 inches
1	100	100	100	100	100	100	100	100	100								
2	25	57	70	80	86	89	92	95	98								
3	2	22	41	55	64	71	77	82	86	89	92	95					
4		7	21	35	46	54	62	68	72	78	82	86	90	96			
5		1	10	22	32	41	49	55	61	66	70	76	82	88	94		
6			4	13	22	30	38	45	51	57	62	67	72	79	86	92	
7			1	8	15	22	29	37	43	49	54	59	65	71	79	86	92
8				4	10	15	22	28	35	41	46	51	57	63	69	77	84
9				1	6	11	16	22	28	33	39	44	50	56	62	68	76
10					3	7	11	16	21	27	32	37	42	48	54	61	67
11					1	4	8	12	16	21	26	31	36	41	47	53	59
12						2	5	9	12	17	21	25	30	35	41	46	52
13						1	3	6	9	13	16	20	24	29	34	39	45
14							1	4	6	9	12	16	20	24	28	33	38
15								2	4	6	9	12	15	19	23	27	31
16								1	2	4	6	9	12	15	18	22	25
17									1	3	4	6	9	11	14	17	20
18										1	3	4	6	8	11	13	16
19											1	3	4	6	8	10	12
20												1	3	4	6	8	9
21													1	3	4	5	7
22														1	2	3	4
23															1	2	3
24																1	1

TABLE 29.—*Percentage distribution of trees in and above successive diameter classes in stands of different average diameter; lowland white fir only*

Diameter class (inches)	Distribution (per cent) by average stand diameter															
	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	13 inches	14 inches	15 inches	16 inches	17 inches
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2	40	62	73	80	85	88	90	91	91	92	92	93	93	94	94	95
3		24	41	52	60	67	72	75	78	79	80	80	81	82	82	83
4		5	23	38	47	55	60	64	67	68	70	71	71	72	73	74
5			9	25	36	44	51	55	58	59	61	62	63	64	65	65
6			3	15	27	36	44	48	51	53	55	56	57	58	59	59
7				7	19	29	37	42	45	47	49	50	51	52	53	54
8				3	12	22	31	36	40	42	44	45	46	47	48	49
9				1	7	16	25	31	35	37	40	41	42	43	44	45
10					4	11	21	27	30	33	35	37	38	39	40	41
11					1	7	16	22	26	29	31	33	34	35	37	38
12						5	12	18	22	25	28	29	31	32	33	34
13						3	8	14	18	21	24	26	27	28	30	31
14						1	6	11	15	18	21	22	24	25	27	28
15							4	8	12	15	17	19	21	22	23	25
16							3	6	9	12	14	16	18	19	21	22
17							2	4	7	9	12	14	15	17	18	19
18							1	3	5	7	9	11	13	14	15	16
19								2	4	5	7	9	10	12	13	14
20								1	3	4	6	7	8	10	11	12
21									2	3	5	6	7	8	9	10
22									1	2	3	4	5	6	7	8
23										1	2	3	4	5	6	7
24											1	2	3	4	5	5
25												1	2	3	4	4

TABLE 30.—*Percentage distribution of trees in and above successive diameter classes in stands of different average diameter; Douglas fir only*

Diameter class (inches)	Distribution (per cent) by average stand diameter																
	1 inch	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	13 inches	14 inches	15 inches	16 inches	17 inches	18 inches
1	100	100	100	100	100	100	100	100	----	----	----	----	----	----	----	----	----	----
2	4	50	79	89	94	97	98	99	----	----	----	----	----	----	----	----	----	----
3	----	14	48	72	84	91	95	97	99	99	----	----	----	----	----	----	----	----
4	----	2	21	46	69	82	90	94	97	98	99	----	----	----	----	----	----	----
5	----	----	7	26	49	69	82	89	94	97	98	99	99	99	----	----	----	----
6	----	----	2	13	33	53	71	83	90	94	96	97	98	98	99	99	99	----
7	----	----	----	6	20	39	59	74	84	91	94	96	97	97	98	98	98	99
8	----	----	----	2	11	27	46	63	77	86	90	93	94	96	96	97	97	98
9	----	----	----	----	6	18	34	51	66	79	85	89	91	93	94	95	95	96
10	----	----	----	----	3	11	25	41	56	72	80	84	87	90	91	92	93	94
11	----	----	----	----	1	7	18	33	46	64	73	79	82	86	87	89	90	91
12	----	----	----	----	----	4	11	24	37	54	65	71	76	80	82	84	86	88
13	----	----	----	----	----	2	7	17	29	44	56	63	69	74	76	79	81	83
14	----	----	----	----	----	----	5	12	22	36	47	54	61	67	70	73	75	78
15	----	----	----	----	----	----	3	8	16	29	38	45	52	59	62	66	68	71
16	----	----	----	----	----	----	1	5	12	22	32	38	44	51	54	58	62	65
17	----	----	----	----	----	----	----	3	8	17	25	31	37	43	46	50	53	57
18	----	----	----	----	----	----	----	2	6	13	20	25	30	36	39	43	46	50
19	----	----	----	----	----	----	----	1	4	9	15	19	24	30	32	36	39	42
20	----	----	----	----	----	----	----	----	3	6	11	15	19	24	26	30	32	36
21	----	----	----	----	----	----	----	----	1	5	8	11	14	19	21	24	26	30
22	----	----	----	----	----	----	----	----	----	3	5	8	11	14	16	19	21	24
23	----	----	----	----	----	----	----	----	----	2	4	6	8	11	12	15	17	19
24	----	----	----	----	----	----	----	----	----	1	2	4	6	8	9	11	13	15
25	----	----	----	----	----	----	----	----	----	----	1	3	4	6	7	8	10	11
26	----	----	----	----	----	----	----	----	----	----	----	2	3	4	5	6	7	9
27	----	----	----	----	----	----	----	----	----	----	----	1	2	3	3	5	5	6
28	----	----	----	----	----	----	----	----	----	----	----	----	1	2	2	4	4	5
29	----	----	----	----	----	----	----	----	----	----	----	----	----	1	1	3	3	4
30	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	3	3

TABLE 31.—*Percentage distribution of trees in and above successive diameter classes in stands of different average diameter; western red cedar only*

Diameter class (inches)	Distribution (per cent) by average stand diameter																
	1 inch	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	13 inches	14 inches	15 inches	16 inches	17 inches
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	----	----	----
2	3	21	37	53	63	70	75	79	82	84	86	90	94	98	----	----	----
3	----	1	5	11	20	29	38	45	52	58	65	71	80	91	98	----	----
4	----	----	1	4	8	13	20	27	35	42	48	56	66	79	92	98	----
5	----	----	----	1	4	7	11	17	23	31	38	46	55	68	83	95	----
6	----	----	----	----	2	5	8	11	17	22	29	37	45	58	73	89	98
7	----	----	----	----	----	3	5	8	12	16	22	29	37	48	63	80	94
8	----	----	----	----	----	2	4	6	9	12	17	24	31	41	55	70	88
9	----	----	----	----	----	1	2	4	7	9	13	18	25	34	46	61	78
10	----	----	----	----	----	----	1	3	5	7	10	15	20	28	38	51	68
11	----	----	----	----	----	----	----	2	4	6	8	12	16	23	32	43	59
12	----	----	----	----	----	----	----	1	3	4	7	9	13	18	25	36	49
13	----	----	----	----	----	----	----	----	2	3	5	7	10	14	19	28	39
14	----	----	----	----	----	----	----	----	1	2	4	6	8	10	15	21	30
15	----	----	----	----	----	----	----	----	----	1	3	4	6	8	10	15	21
16	----	----	----	----	----	----	----	----	----	----	2	3	4	6	8	10	15
17	----	----	----	----	----	----	----	----	----	----	1	2	3	4	6	8	10
18	----	----	----	----	----	----	----	----	----	----	----	1	2	3	4	5	7
19	----	----	----	----	----	----	----	----	----	----	----	----	1	2	2	3	4
20	----	----	----	----	----	----	----	----	----	----	----	----	----	1	1	2	3
21	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1	2
22	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1

TABLE 32.—*Percentage distribution of basal area in and above successive diameter classes in stands of different average diameter; all species combined*

Diameter class (inches)	Distribution (per cent) by average stand diameter																		
	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	13 inches	14 inches	15 inches	16 inches	17 inches	18 inches	19 inches	20 inches
1	100	100	100	100															
2	95	96	97	98															
3	78	88	93	96	97	98													
4	49	73	84	91	94	96	98												
5	20	52	72	83	89	93	95	97	98										
6	7	32	57	73	82	88	92	95	96	98									
7		17	39	60	72	81	87	91	94	96	97	98							
8		8	25	46	62	73	81	87	91	94	96	97	98						
9		3	15	32	50	63	73	80	85	90	93	95	97	98					
10			8	20	38	50	62	72	79	85	89	92	94	96	98				
11			4	13	25	39	52	63	72	79	84	88	91	94	96	97	98		
12				8	17	29	42	54	63	72	78	83	88	91	94	96	97	98	
13				5	11	20	32	44	54	65	72	78	83	88	91	93	95	97	98
14				2	8	15	24	34	45	56	64	71	78	83	88	91	93	95	97
15					5	10	18	27	37	48	57	65	72	79	84	88	91	93	95
16					3	7	13	21	29	40	49	58	66	73	79	83	87	91	93
17						4	9	15	22	32	40	49	58	66	73	78	83	87	91
18						3	6	11	16	22	32	40	49	58	66	72	78	83	87
19							3	7	11	18	24	32	40	50	58	65	71	77	82
20							2	5	8	13	18	22	32	41	50	57	64	71	77
21								3	5	9	13	18	24	32	40	47	55	62	70
22									3	6	9	13	18	22	32	38	46	54	62
23										4	6	9	13	17	23	29	36	44	52
24										2	4	6	9	12	17	22	28	34	42
25											2	4	6	9	12	16	20	26	32
26												2	4	6	9	11	15	19	24
27													2	3	5	8	10	14	18
28														2	3	5	7	9	13
29															2	3	5	7	9
30																	3	4	6

TABLE 33.—*Percentage distribution of cubic-foot volume in and above successive diameter classes in stands of different average diameter; all species combined*

Diameter class (inches)	Distribution (per cent) by average stand diameter																		
	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	13 inches	14 inches	15 inches	16 inches	17 inches	18 inches	19 inches	20 inches
1	100																		
2	98																		
3	82	93	96																
4	54	81	91	95	98														
5	26	64	82	90	95	97													
6	9	44	70	82	89	93	97												
7	2	26	54	72	82	89	94	96	98										
8		13	37	58	73	82	89	93	96	97									
9		5	24	42	60	72	82	88	92	95	97								
10		2	14	31	48	63	74	82	88	92	94	96	98						
11			7	20	34	50	64	74	81	87	91	94	96	98					
12			3	12	24	38	53	64	74	80	86	90	93	95	97				
13				7	16	28	42	54	64	73	79	86	89	93	95	97			
14				3	10	20	32	43	55	64	72	79	85	89	92	95	97	98	
15				2	6	13	23	33	44	54	64	72	78	84	88	92	94	96	98
16					3	9	17	26	36	45	55	64	72	78	84	88	92	94	96
17					2	5	11	18	27	36	46	55	63	71	77	83	88	91	94
18						2	7	13	20	28	36	46	54	64	71	77	82	87	91
19						2	4	8	14	20	28	36	45	54	62	70	76	82	86
20							2	5	9	15	21	28	36	46	52	62	69	76	81
21								3	6	9	15	20	28	36	44	52	60	68	74
22								2	3	6	10	15	21	28	36	44	52	60	68
23									2	4	7	11	16	22	28	35	43	51	59
24										2	4	7	10	15	20	27	34	42	50
25											2	4	7	11	15	20	26	34	41
26												2	4	7	10	15	20	25	32
27													2	4	6	9	13	18	23
28														2	3	5	8	12	16
29															2	3	5	8	11
30																2	3	4	6

TABLE 34.—*Percentage distribution of board-foot volume in and above successive diameter classes in stands of different average diameter; all species combined*

Diameter class (inches)	Distribution (per cent) by average stand diameter																
	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches	8 inches	9 inches	10 inches	11 inches	12 inches	13 inches	14 inches	15 inches	16 inches	17 inches	18 inches
7	100	100	100	100	100	100	100										
8	37	69	83	89	94	97	98										
9	9	32	58	72	83	89	92	94	97	98							
10	3	14	35	53	67	77	84	89	93	94	97	98					
11		6	19	35	50	64	74	81	86	91	93	95	97	98			
12		3	10	21	36	50	61	71	78	84	89	92	94	96	97	98	
13			5	13	24	36	49	60	69	76	83	87	91	93	95	96	97
14			3	7	15	25	37	48	58	68	75	81	86	90	93	94	96
15				4	9	16	26	36	47	57	67	74	80	85	89	92	94
16				3	5	11	19	27	37	47	57	65	72	80	84	88	91
17					3	7	12	19	28	37	47	56	65	72	79	84	87
18					2	4	8	14	20	29	38	47	55	65	72	78	83
19						3	5	9	14	21	29	37	46	56	65	71	77
20							3	6	9	15	21	29	38	47	56	65	71
21							2	4	6	10	15	21	28	38	47	56	64
22								3	4	7	11	16	22	29	39	47	56
23									3	4	7	11	15	21	30	39	46
24										3	4	7	11	15	21	30	37
25											3	4	7	10	14	21	28
26												3	4	6	8	14	20
27													3	4	5	8	14

VOLUME TABLES

CUBIC-FOOT VOLUMES

Tables giving volumes of individual trees of the different species in the western white pine type are presented in the following pages.

TABLE 35.—*Cubic-foot volume table for second-growth western white pine*

Diameter breast high (inches)	Volume (cubic feet) by total height of trees in feet																			Basis (trees)
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	
1	0.02	0.04	0.07	0.10																	
2	.10	.20	.30	0.40	0.49	0.59															14
3	.23	.46	.68	.90	1.12	1.34															11
4		.82	1.20	1.60	2.00	2.40	2.80	3.10													16
5		1.24	1.90	2.50	3.10	3.70	4.32	4.94													46
6			2.7	3.6	4.4	5.3	6.2	7.0	7.8	8.7											28
7			4	5	6	7	8	9	10	12	13	14									53
8			5	6	8	9	11	12	14	15	17	18	20								63
9				8	10	12	14	15	17	19	21	23	25	27							56
10				10	12	14	17	19	21	23	26	28	30	32							46
11						17	20	23	25	28	31	33	36	39							55
12						21	24	27	30	33	36	39	43	46	49						59
13						24	28	31	35	38	42	46	50	53	56						51
14							32	36	40	44	48	52	56	60	64	68					46
15								41	46	50	55	59	64	68	73	77					40
16									52	57	62	67	72	77	82	87					33
17									58	63	69	74	80	86	92	97					31
18									64	70	77	83	89	95	101	107					10
19									70	77	84	90	97	104	111	118	123				17
20										85	92	99	106	114	122	129	136				4
21										93	101	108	116	125	133	141	149				12
22										102	110	118	127	136	145	153	162				10
23										110	119	128	137	147	157	166	175				5
24											130	140	149	158	168	179	188	199			3
25											139	149	159	170	181	191	201	212			
26											149	161	172	182	193	204	215	225			
27											159	172	184	195	206	217	229	240	251	263	1
28												184	196	208	219	231	243	255	268	280	1
29												195	208	220	232	245	258	271	284	298	
30												207	220	233	246	260	273	287	300	314	
31												218	232	247	260	275	290	304	318	332	
32												229	244	260	275	290	305	320	335	350	
Basis (trees)		15	16	27	48	38	55	66	80	88	81	74	58	38	24	2		1			711

Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Volume includes peeled stump, stem, and top. Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, less than 0.5 per cent. Average deviation of individual tree volumes from tabular values 7.4 per cent.

TABLE 36.—*Cubic-foot volume table for second-growth western larch*

Diameter breast high (inches)	Volume (cubic feet) by total height of trees in feet																				Basis (trees)
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	
1	0.01	0.03	0.06																		
2		.13	.20	0.30																	
3		.35	.48	.67	0.84																3
4		.60	.92	1.20	1.54	1.90															4
5			1.51	1.90	2.48	2.95															11
6				2.8	3.6	4.2	4.8	5.5	6.3	7.2											13
7				3.9	4.8	5.7	6.6	7.6	8.6	9.6	10.5										12
8				5	6	8	9	10	11	13	14										25
9				6	8	10	11	13	14	16	18	19									22
10					10	12	14	16	17	19	21	23	25	27							11
11					12	14	16	19	21	23	26	28	30	33	35	37					32
12						17	19	22	25	27	30	33	36	38	41	44					22
13						20	23	26	29	32	35	38	42	45	48	51					22
14						22	26	29	33	36	40	44	48	51	54	58					28
15						25	29	33	37	41	45	49	54	58	62	66					13
16							33	38	42	46	50	55	60	65	69	73	78	83	87		17
17									46	52	57	62	67	72	76	81	86	91	96		18
18									51	57	63	68	74	79	84	89	94	99	105		15
19									57	64	70	75	81	87	92	98	103	109	114		10
20									63	70	76	82	89	95	100	106	112	119	125		14
21										76	83	90	96	103	109	116	122	129	135		15
22										83	90	97	104	111	118	125	132	139	146		11
23										90	97	105	112	120	127	134	142	150	158		3
24										97	105	113	121	129	137	144	152	161	169		2
25											112	121	129	138	146	155	163	172	181		5
26											120	129	138	147	156	165	174	183	192	201	5
27											127	137	147	157	166	176	185	194	203	212	4
28											135	145	156	166	176	186	196	206	216	225	1
29											142	153	165	176	186	197	207	217	228	238	2
30											150	162	174	186	197	208	218	229	240	251	
31												171	183	195	207	219	230	241	252	264	
32												180	193	205	218	230	241	252	264	278	1
Basis (trees)		1		7	11	24	21	24	28	33	43	24	37	32	35	17	2	2			341

Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Volume includes peeled stump, stem, and top. Tree volumes computed by planimeter method. Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.6 per cent. Average deviation of individual tree volumes from tabular values, 8.4 per cent.

TABLE 37.—*Cubic-foot volume table for second-growth western hemlock*

Diameter breast high (inches)	Volume (cubic feet) by total height of trees in feet																Basis (trees)
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
1	0.04	0.06															
2	.13	.20	0.27														
3		.46	.62	0.77													4
4		.82	1.09	1.37													2
5		1.28	1.68	2.12													2
6		1.8	2.4	3.1	3.7	4.4											1
7		2.0	3	4	5	6	7	8									1
8		3	4	5	7	8	9	11									1
9				7	9	10	12	14	16	18							3
10				8	11	13	15	17	19	22							2
11					13	15	18	20	23	26							1
12					15	18	21	24	28	31							2
13					18	22	25	29	33	36	40						2
14					21	25	29	33	38	42	47	51					4
15					24	29	33	38	43	48	54	59					6
16					28	33	38	43	49	55	61	67	74	80	88		11
17					31	37	43	49	55	62	69	76	83	90	98		5
18					34	41	48	55	62	69	77	85	93	101	110		5
19					38	45	53	61	69	77	86	94	103	112	122		7
20							58	67	76	85	95	104	114	124	134		3
21							64	74	84	94	105	115	126	136	147	159	6
22							70	81	92	103	114	126	137	149	161	174	
23							77	89	101	112	124	137	150	163	176	190	2
24									109	122	135	149	163	177	191	206	1
25									119	132	146	161	176	191	207	223	
26									128	143	159	174	190	206	223	240	1
27												187	204	222	240	259	
28												200	220	239	259	279	
29												215	236	257	278	299	
30												230	252	274	297	320	
Basis (trees)		7	2		4	3	3	3	13	8	14	9	5	1			72

Block indicates extent of basic data. Data collected principally on the Coeur d'Alene and Kaniksu National Forests in stands from 30 to 160 years of age. Volume includes peeled stump, stem, and top. Tree volumes computed by planimeter method. Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, 0.31 per cent. Average deviation of individual tree volumes from tabular values, 8.2 per cent.

125913°—32——3

TABLE 38.—*Cubic-foot volume table for second-growth lowland white fir*

Diameter breast high (inches)	Volume (cubic feet) by total height of trees in feet																		Basis (trees)
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	
1	0.03	0.06																	
2	.12	.22	0.32	0.42															
3	.25	.47	.69	.91															14
4		.84	1.22	1.64	2.0	2.4													3
5		1.32	1.87	2.52	3.1	3.8													2
6			2.7	3.6	4.4	5.3	6	7	8										6
7			4	5	6	7	8	9	10										5
8			5	6	8	9	10	12	14	15	17								7
9			6	8	10	12	13	15	17	19	21								8
10				.10	12	14	16	18	21	23	25								10
11					14	17	19	22	25	28	31								13
12						20	23	26	30	33	36								4
13						23	27	31	34	38	42	46	50	54					6
14						27	31	35	40	44	49	54	58	62					2
15						31	36	41	46	51	56	62	67	71					9
16							41	47	52	58	64	70	76	81					4
17							46	53	59	66	72	79	85	91	97				6
18							52	59	66	74	81	88	94	101	108				8
19									74	82	90	97	104	111	119	127			7
20									81	90	99	107	114	122	130	139			4
21									89	99	108	117	125	133	142	150			6
22									97	108	117	126	135	144	153	162			5
23									106	117	127	137	146	156	165	175	186	196	5
24									113	125	137	148	158	168	178	189	200	210	1
25									121	134	147	159	170	181	192	203	214	226	2
26											158	170	183	195	207	219	231	243	1
27											168	182	196	209	222	234	247	261	1
28											179	195	209	223	238	251	265	280	
29											190	207	222	237	253	269	284	299	
30											202	219	236	252	269	287	302	318	
Basis (trees)	1	15	3	5	5	8	10	12	18	17	9	16	13	3	4				139

Block indicates extent of basic data. Data collected principally on the Coeur d'Alene and Kaniksu National Forests in stands from 30 to 160 years of age. Volume includes peeled stump, stem, and top. Tree volumes computed by planimeter method. Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, 0.02 per cent. Average deviation of individual tree volumes from tabular values, 8.0 per cent.

TABLE 39.—*Cubic-foot volume table for second-growth Douglas fir*

Diameter, breast high (inches)	Volume (cubic feet) by total height of trees in feet																	Basis (trees)
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	
1	0.01	0.06	0.09																
2	.09	.24	.32	0.42															
3		.48	.67	.88	1.10														1
4		.80	1.15	1.51	1.88	2.2	2.6												6
5		1.20	1.75	2.31	2.82	3.4	4.0												26
6			2.5	3.3	4.0	4.8	5.6	6	7										23
7			3.4	4.4	5.4	6.4	7.4	8	9										19
8			4	6	7	8	10	11	12	13	15								46
9				7	9	10	12	14	15	17	18								30
10				9	11	13	15	16	18	20	22								19
11					13	15	17	20	22	24	26	28	30						37
12					15	18	20	23	26	28	31	33	36						25
13					17	20	24	27	30	33	35	38	41						23
14					20	24	27	30	34	38	41	45	48						26
15					22	27	31	35	39	43	46	50	54						21
16						30	35	39	44	48	52	57	61	66	70	74			12
17							39	44	49	54	58	63	68	73	78	82			11
18							43	49	54	60	65	71	76	81	86	91			8
19								54	60	66	72	78	84	90	96	101			9
20								59	66	72	79	86	92	99	105	111			5
21								64	72	79	86	94	101	108	115	121			9
22								70	78	86	94	102	110	118	126	132			2
23								76	85	94	103	112	120	128	137	144			4
24								82	91	101	111	121	130	139	148	156			3
25								88	99	110	120	130	140	149	159	168			1
26								95	106	118	129	140	150	160	170	179			1
27								102	114	126	138	150	161	172	182	192			
28								110	122	135	148	160	172	183	195	206	217	228	
29									130	144	158	171	183	196	208	220	232	243	
30									138	154	168	182	195	208	221	235	248	260	1
31										164	179	193	207	221	235	250	264	276	
32										174	189	204	219	235	250	266	281	294	
Basis (trees)			3	22	42	41	51	58	61	48	28	9	2	2	1				368

Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Volume includes peeled stump, stem, and top. Tree volumes computed by planimeter method. Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.6 per cent. Average deviation of individual tree volumes from tabular values, 9.9 per cent.

TABLE 40.—*Cubic-foot volume table for second-growth western red cedar*

Diamter, breast high (inches)	Volume (cubic feet) by total height of trees in feet																Basis (trees)
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
1	0.02	0.05															
2	.10	.20	0.31														
3		.47	.67	0.91													1
4		.83	1.25	1.63	2.1	2.5											1
5		1.27	1.95	2.60	3.2	3.8											5
6			2.8	3.6	4.5	5.3	6	7									8
7			4	5	6	7	8	9									3
8			5	6	8	9	10	12	13	14							4
9			6	8	9	11	13	14	16	18							13
10			7	9	11	14	16	18	20	22							10
11				11	14	16	19	21	23	26	29						12
12				13	16	19	22	25	27	30	33	36	38				27
13				15	18	22	25	28	32	35	38	41	44				23
14					21	25	29	33	36	40	43	47	50				20
15					24	29	33	37	41	45	49	53	56				19
16					27	32	37	41	46	50	54	58	62				17
17					30	35	40	45	50	55	60	64	69				11
18					33	39	45	50	55	60	65	70	76				11
19					36	43	49	55	61	66	71	77	83				3
20							53	60	66	72	78	84	90				3
21							58	65	72	78	84	91	98				2
22									77	84	91	98	106	114			3
23									83	91	99	107	115	123			3
24									90	98	106	115	123	131	139	146	1
25									96	105	114	123	132	140	149	156	
26									103	113	122	131	140	149	158	167	
27									110	120	130	140	149	159	168	178	
28									117	128	138	148	158	168	178	188	1
29									125	136	146	157	167	178	188	199	1
30									132	143	154	165	176	187	198	209	
Basis (trees)		1	2	8	15	13	37	54	41	21	7	2	1				202

Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Volume includes peeled stump, stem, and top. Tree volumes computed by planimeter method. Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.05 per cent. Average deviation of individual tree volumes from tabular values 8.0 per cent.

BOARD-FOOT VOLUMES, SCRIBNER RULE

TABLE 41.—*Board-foot volume table (Scribner rule—total height) for second-growth western white pine*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet																Basis (trees)
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	
8	9	17	24	32	40	48	55	62	69	76								62
9	20	30	40	50	60	68	78	86	96	108	117							56
10	31	43	56	68	80	90	105	115	125	140	150							46
11			72	87	100	115	130	145	155	170	185							55
12			88	105	125	140	155	175	190	210	225	240						59
13			105	125	145	165	185	205	225	245	265	285						51
14				145	170	190	215	240	260	285	310	330	360					46
15					190	220	250	275	305	330	355	380	410					40
16						250	285	320	345	380	410	435	465					33
17						290	325	360	395	430	460	495	525					31
18						325	370	410	445	480	515	550	595					10
19						365	410	455	495	540	580	615	670	705				17
20							460	510	550	600	645	690	740	790				4
21							510	565	615	665	715	765	820	870				12
22							560	620	675	740	790	845	905	960				10
23							615	680	740	810	865	930	990	1,050				5
24								745	810	880	945	1,010	1,070	1,140	1,200			3
25								810	880	955	1,020	1,090	1,160	1,220	1,300			
26								875	950	1,030	1,100	1,170	1,250	1,310	1,390			
27								940	1,020	1,100	1,180	1,250	1,340	1,410	1,490	1,560	1,640	1
28									1,090	1,180	1,260	1,340	1,430	1,500	1,590	1,660	1,750	1
29									1,160	1,250	1,350	1,430	1,520	1,600	1,690	1,770	1,850	
30									1,240	1,330	1,430	1,520	1,610	1,700	1,790	1,870	1,950	
31									1,310	1,410	1,510	1,610	1,710	1,800	1,890	1,970	2,050	
32									1,380	1,490	1,590	1,700	1,800	1,890	1,980	2,060	2,140	
Basis (trees)		3	10	33	51	79	88	81	74	58	38	24	2		1			542

Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1 foot. Trees scaled in 16-foot log lengths with 0.25-foot trimming allowance and additional top section to 6-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, 0.44 per cent. Average deviation of individual tree volumes from tabular values, 11.6 per cent.

125913°—32——4

TABLE 42.—*Board-foot volume table (Scribner rule—total height) for second-growth western larch*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet																Basis (trees)
	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	
10	9	13	18	23	29	35	41	47	54	62							2
11	19	26	34	42	51	60	69	79	89	100	110	120					32
12		43	53	64	75	86	100	115	130	140	155	170					22
13		60	74	88	100	115	135	150	165	185	200	220					22
14		80	95	115	130	150	165	185	205	225	250	270					28
15		100	120	140	160	180	200	220	240	265	290	320					13
16			140	165	185	210	230	255	280	310	340	370	405	445	490		17
17					215	245	270	300	330	360	390	430	470	515	565		18
18					250	280	310	345	375	405	445	485	530	580	635		15
19					280	315	350	385	420	460	500	545	595	655	715		10
20					310	350	390	430	470	510	555	610	665	725	790		14
21						395	435	480	525	570	620	675	730	790	860		15
22						440	485	530	575	625	675	740	805	870	940		11
23						480	530	580	635	685	740	800	870	940	1,020		3
24						525	575	630	685	740	800	870	940	1,010	1,090		2
25							630	680	740	800	860	930	1,000	1,080	1,170		5
26							680	730	795	855	920	995	1,070	1,150	1,240	1,330	5
27							730	785	850	915	985	1,060	1,140	1,220	1,310	1,410	4
28							780	840	905	970	1,040	1,120	1,200	1,290	1,380	1,480	1
29							820	890	960	1,030	1,100	1,180	1,270	1,360	1,460	1,560	2
30							870	940	1,010	1,080	1,160	1,240	1,330	1,430	1,530	1,640	
31								990	1,070	1,140	1,220	1,310	1,400	1,490	1,600	1,710	
32								1,040	1,120	1,200	1,280	1,370	1,470	1,570	1,670	1,780	1
Basis (trees)			4	6	19	24	40	24	37	32	35	17	2	2			242

Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths, with 0.3-foot trimming allowance, and additional top section to 8-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, 0.7 per cent. Average deviation of individual tree volumes from tabular values, 15.7 per cent.

TABLE 43.—*Board-foot volume table (Scribner rule—total height) for second-growth western hemlock*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet													Basis (trees)
	40	50	60	70	80	90	100	110	120	130	140	150	160	
10	15	24	33	41	49	57	65							2
11		38	49	60	70	81	91							1
12		52	65	80	92	105	120							2
13		66	83	100	115	135	155	175						2
14		80	100	125	145	165	190	210	235					4
15		95	120	150	175	200	230	255	280					6
16		110	140	170	200	230	265	295	330	360	390	420		11
17		125	165	200	235	270	305	340	380	415	450	490		5
18		145	185	225	265	305	350	390	430	475	515	560		5
19		160	210	255	300	345	395	445	490	540	585	635		7
20				290	340	390	450	500	555	610	660	720		3
21				325	380	440	505	565	625	690	750	810	875	6
22				360	430	495	565	630	700	770	840	915	990	
23				405	480	550	630	705	780	860	940	1,020	1,100	2
24						610	700	780	865	955	1,040	1,130	1,220	1
25						675	770	865	955	1,050	1,150	1,250	1,350	
26						740	845	950	1,050	1,150	1,250	1,360	1,470	1
27									1,140	1,260	1,370	1,480	1,600	
28									1,240	1,370	1,490	1,610	1,740	
29									1,340	1,480	1,610	1,740	1,890	
30									1,460	1,600	1,750	1,890	2,040	
Basis (trees)			3	2	3	13	8	14	9	5	1			58

Block indicates extent of basic data. Data collected principally on the Coeur d'Alene and Kaniksu National Forests in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance and additional top section to 8-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.23 per cent. Average deviation of individual tree volumes from tabular values, 11.8 per cent.

TABLE 44.—*Board-foot volume table (Scribner rule—total height) for second-growth lowland white fir*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet															Basis (trees)
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	
10	13	18	24	31	37	45	53	60								8
11		37	46	55	64	74	85	96								13
12			70	82	95	110	125	140								4
13			95	110	125	145	160	180	200	220	240					6
14			120	140	160	180	200	225	250	270	295					2
15			145	170	195	220	245	270	295	320	350					9
16				200	230	260	290	320	350	380	415					4
17				235	265	300	340	370	405	440	480	515				6
18				265	305	345	385	425	465	505	545	590				8
19						390	440	480	525	570	620	660	705			7
20						440	500	540	590	640	690	740	790			4
21						495	555	605	655	715	770	825	880			6
22						555	615	670	730	790	850	910	970			5
23						610	680	740	800	870	940	1,000	1,060	1,130	1,190	5
24						670	745	810	875	950	1,020	1,090	1,160	1,230	1,290	1
25						730	810	880	950	1,030	1,110	1,180	1,250	1,330	1,400	2
26								950	1,030	1,110	1,190	1,270	1,350	1,430	1,500	1
27								1,020	1,110	1,200	1,280	1,370	1,450	1,530	1,610	1
28								1,100	1,190	1,280	1,380	1,470	1,560	1,640	1,720	
29								1,170	1,270	1,370	1,470	1,560	1,660	1,740	1,820	
30								1,240	1,350	1,460	1,560	1,660	1,760	1,850	1,930	
Basis (trees)			1	4	8	17	17	9	16	13	3	4				92

Block indicates extent of basic data. Data collected principally on the Coeur d'Alene and Kaniksu National Forests in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance and additional top section to 8-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.18 per cent. Average deviation of individual tree volumes from tabular values, 15.8 per cent.

TABLE 45.—*Board-foot volume table (Scribner rule—total height) for second-growth Douglas fir*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet															Basis (trees)
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	
10	1	4	9	14	23	31	40	48								17
11		12	21	34	46	60	70	83	98	110						37
12		23	36	54	70	88	105	120	135	150						25
13		35	55	76	95	115	135	155	175	190						23
14		49	74	99	120	145	170	190	215	235						26
15		65	94	120	145	175	205	230	255	275						21
16			115	145	175	205	235	265	290	320	350	375	400			12
17				170	205	240	270	305	335	365	390	420	450			11
18				195	230	270	305	340	375	410	440	470	500			8
19					260	300	340	380	420	450	485	525	560			9
20					290	335	380	425	460	500	540	580	615			5
21					325	370	420	465	510	555	595	640	680			9
22					355	405	460	510	560	605	650	700	740			2
23					390	445	500	555	610	660	710	760	810			4
24					425	485	545	605	660	715	770	825	875			3
25					455	520	585	650	710	770	825	885	940			1
26					490	560	630	700	760	820	885	950	1,010			1
27					530	605	680	750	810	880	940	1,010	1,080			
28					565	645	725	800	865	940	1,000	1,080	1,140	1,210	1,280	
29						685	770	850	920	1,000	1,070	1,140	1,210	1,280	1,360	
30						730	815	900	975	1,060	1,130	1,210	1,280	1,360	1,440	1
31								860	950	1,030	1,120	1,200	1,280	1,350	1,430	1,520	
32								910	1,000	1,090	1,180	1,260	1,340	1,430	1,510	1,600	
Basis (trees)			8	19	40	58	48	28	9	2	2	1				215

Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths, with 0.3-foot trimming allowance, and additional top section to 8-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, 0.7 per cent. Average deviation of individual tree volumes from tabular values, 23.3 per cent.

TABLE 46.—*Board-foot volume table (Scribner rule—total height) for second-growth western red cedar*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet														Basis (trees)
	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
10	4	10	16	22	28	34	40	47							7
11		21	28	36	44	53	62	72	83						12
12		32	42	53	64	76	89	100	115	130	145				26
13		43	56	70	86	100	115	130	145	165	180				23
14			71	88	105	125	140	160	175	195	215				20
15			87	105	125	145	165	185	210	230	250				19
16			100	125	150	170	190	215	240	260	285				17
17			120	145	170	195	220	245	270	295	320				11
18			135	160	190	215	245	270	300	325	355				11
19			150	185	215	240	270	300	330	360	395				3
20					235	270	300	330	365	400	435				3
21					260	295	330	365	400	440	480				2
22							360	395	435	480	520	565			3
23							390	430	475	520	565	610			3
24							425	465	510	560	610	660	710	765	1
25							455	500	550	600	650	705	760	820	
26							490	535	585	640	700	755	815	875	
27							520	570	625	680	740	800	865	930	
28							555	605	665	725	785	850	920	990	1
29							585	645	705	770	835	900	975	1,050	1
30							620	680	750	815	880	950	1,030	1,110	
Basis (trees)				4	34	53	41	21	7	2	1				163

Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance and additional top section to 8-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, less than 1 per cent. Average deviation of individual tree volumes from tabular values, 15.6 per cent.

TABLE 47.—*Board-foot volume table (Scribner decimal C rule) for second-growth western white pine*

Diameter breast high (inches)	Volume (board feet in tens) by total number of 16-foot logs										Basis (trees)
	1¼	2	3	4	5	6	7	8	9	10	
8	2	4	7	10	13						61
9	2	4	8	11	14						56
10	3	5	9	12	16	20					46
11	3	5	10	14	18	22					55
12	3	6	11	15	20	24	29				59
13	4	7	12	17	22	27	32				51
14	4	7	13	19	25	30	36	41			46
15	4	8	15	21	27	33	40	45			40
16				23	30	37	44	50	57	64	33
17				25	33	41	48	56	63	71	31
18				28	36	45	54	62	70	78	10
19				30	40	49	59	68	77	86	17
20				33	44	54	65	75	85	95	4
21				36	48	59	71	82	93	105	12
22				39	52	64	78	90	100	115	10
23				42	57	70	85	98	110	125	5
24				46	61	76	92	105	120	135	3
25				50	66	82	100	115	130	145	
26				54	71	89	110	125	140	160	
27				58	77	95	115	135	155	170	1
28				62	82	105	125	145	165	185	1
29				66	88	110	130	155	175	195	
30				70	94	115	140	165	185	210	
31				75	100	125	150	175	200	220	
32				79	105	135	160	185	210	235	
Basis (trees)	15	77	85	124	108	82	41	9			541

Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1 foot. Trees scaled in 16-foot log lengths with 0.25-foot trimming allowance and additional top section to 6-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.13 per cent. Average deviation of individual tree volume from tabular values, 8.5 per cent.

TABLE 48.—*Board-foot volume table (Scribner decimal C rule) for second-growth western larch*

Diameter breast high (inches)	Volume (board feet in tens) by total number of 16-foot logs										Basis (trees)
	1¼	2	3	4	5	6	7	8	9	10	
10	4	6	10								2
11	4	7	11	15	19						24
12	5	7	12	17	21	25					22
13	5	8	14	19	23	28	32				21
14	5	9	15	20	26	31	35				28
15	6	9	16	22	28	34	39				13
16		10	17	24	30	37	42	48			17
17		11	18	26	33	40	46	52			18
18		12	20	28	35	43	50	57			15
19			21	30	38	47	54	62			10
20			22	32	41	50	58	67	75	83	14
21				34	44	54	63	73	82	91	15
22				37	48	58	68	79	89	99	11
23				40	51	63	73	85	96	105	3
24				42	55	68	79	92	105	115	2
25				45	59	72	85	99	110	125	5
26				48	62	77	91	105	120	135	5
27				51	66	82	97	115	130	145	4
28				54	71	88	105	120	135	150	1
29				57	75	93	110	130	145	160	2
30				60	79	99	120	135	155	170	
31				63	84	105	125	145	165	180	
32				67	88	110	130	150	170	190	1
Basis (trees)	12	27	25	43	45	42	31	8			233

Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance and additional top section to 8-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.25 per cent. Average deviation of individual tree volumes from tabular values, 8.2 per cent.

TABLE 49.—*Board-foot volume table (Scribner decimal C rule) for second-growth western hemlock*

Diameter breast high (inches)	Volume (board feet in tens) by total number of 16-foot logs								Basis (trees)
	1¼	2	3	4	5	6	7	8	
10	4	8	13						2
11	5	8	14						1
12	5	9	15						2
13	6	10	17	24					2
14	6	11	19	26	34				4
15	7	12	20	29	37	46			6
16	7	12	22	31	41	50	58		11
17	8	13	23	34	44	54	63		5
18	8	14	25	37	48	59	69		5
19		15	27	40	52	64	75		7
20		16	29	43	56	70	82		3
21		17	31	46	61	75	89		6
22		19	34	50	66	82	96		
23			36	54	71	88	105		2
24			39	58	76	95	115		1
25			42	62	82	100	120		
26				66	88	110	130	155	1
27				70	94	120	140	165	
28				74	100	125	150	175	
29				79	105	135	160	190	
30				84	115	145	170	200	
Basis (trees)	3	5	13	18	15	4			58

Block indicates extent of basic data. Data collected principally on the Coeur d'Alene and Kaniksu National Forests in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance and additional top section to 8-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.06 per cent. Average deviation of individual tree volumes from tabular values, 8.6 per cent.

TABLE 50.—*Board-foot volume table (Scribner decimal C rule) for second-growth lowland white fir*

Diameter breast high (inches)	Volume (board feet in tens) by total number of 16-foot logs								Basis (trees)
	1¼	2	3	4	5	6	7	8	
10	4	7	12						6
11	4	8	13	18					12
12	5	8	14	20	26				4
13	5	9	16	22	29				6
14	6	10	17	25	32	39			2
15		11	19	27	35	42			9
16		12	20	29	38	46			4
17		12	22	32	41	50	59	68	6
18		13	24	34	45	55	64	74	8
19		14	26	37	49	60	70	81	7
20		15	28	40	53	66	77	88	4
21			30	43	57	71	84	96	6
22			32	47	62	77	91	105	5
23			34	50	67	83	98	115	5
24			36	54	72	90	105	125	1
25			39	58	77	96	115	135	2
26					83	105	125	145	1
27					88	110	130	155	1
28					94	120	140	165	
29					100	125	150	175	
30					105	135	160	190	
Basis (trees)	6	11	16	12	20	15	9		89

Block indicates extent of basic data. Data collected principally on the Cœur d'Alene and Kaniksu National Forests in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance and additional top section to 8-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.14 per cent. Average deviation of individual tree volumes from tabular values, 8.2 per cent.

TABLE 51.—*Board-foot volume table (Scribner decimal C rule) for second-growth Douglas fir*

Diameter breast high (inches)	Volume (board feet in tens) by total number of 16-foot logs								Basis (trees)
	1¼	2	3	4	5	6	7	8	
10	4	7	11						5
11	4	7	12	16					32
12	5	8	13	18					24
13	5	8	14	20	25				23
14	5	9	15	22	28	34			26
15	6	10	17	24	30	37			21
16		10	18	26	33	40	47		12
17		11	19	28	36	44	51		11
18		12	21	30	39	47	55		8
19		13	22	32	42	51	60		9
20		13	24	35	45	55	65		5
21			26	37	49	60	70	80	9
22			28	40	53	65	76	87	2
23			30	43	57	70	82	95	4
24			32	46	61	75	88	100	3
25			34	49	65	80	95	110	1
26			36	52	69	86	100	120	1
27			38	56	73	92	110	125	
28			40	59	78	98	115	135	
29			43	63	83	105	125	145	
30			46	66	88	110	130	155	1
31			48	70	93	115	140	165	
32			51	74	98	125	150	170	
Basis (trees)	21	54	59	41	18	3	1		197

Block indicates extent of basic data. Data collected throughout the western white-pine region in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance and additional top section to 8-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −1.0 per cent. Average deviation of individual tree volumes from tabular values, 9.8 per cent.

TABLE 52.—*Board-foot volume table (Scribner decimal C rule) for second-growth western red cedar*

Diameter breast high (inches)	Volume (board feet in tens) by total number of 16-foot logs						Basis (trees)
	1¼	2	3	4	5	6	
10	4	7					4
11	4	7	12	16			10
12	5	8	13	18	23		25
13	5	9	15	20	25		23
14	6	10	16	22	27		20
15	6	10	17	24	30		19
16	6	11	18	25	32		17
17	7	12	20	27	35		11
18	7	12	21	30	38		11
19	8	13	22	32	41		3
20	8	14	24	34	44		3
21		15	26	37	48	58	2
22		16	28	40	51	63	3
23			30	42	55	68	3
24			32	45	59	73	1
25			34	48	63	78	
26			36	51	67	83	
27			38	55	71	88	
28			40	58	76	93	1
29			42	61	80	99	1
30			45	64	85	105	
Basis (trees)	18	52	58	23	6		157

Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance and additional top section to 8-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, 0.35 per cent. Average deviation of individual tree volumes from tabular values, 6.7 per cent.

BOARD-FOOT VOLUMES, INTERNATIONAL RULE

TABLE 53.—*Board-foot volume table (international rule) for second-growth western white pine*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet																	Basis (trees)
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	
7	13	18	24	30	36	42	48	53	58									51
8	21	30	38	47	56	65	74	83	91	99								63
9	30	42	54	66	78	91	100	115	130	140	150							56
10	39	56	72	88	100	120	135	150	165	180	195							46
11			90	110	130	150	165	185	205	220	240							55
12			110	135	160	180	200	225	250	270	290	310						59
13			130	160	185	215	240	265	290	320	345	370						51
14				184	220	250	280	310	340	370	400	430	460					46
15					250	290	325	360	395	430	460	495	530					40
16						330	370	410	450	485	525	560	605					33
17						370	415	460	505	545	590	635	680					31
18						420	470	520	570	615	660	710	760					10
19						465	520	575	630	685	740	790	845	900				17
20							575	640	700	755	815	875	935	1,000				4
21							635	700	765	830	900	965	1,030	1,090				12
22							700	770	840	910	980	1,050	1,120	1,190				10
23							760	835	915	990	1,060	1,140	1,220	1,290				5
24								910	995	1,080	1,150	1,230	1,310	1,380	1,450			3
25								985	1,080	1,160	1,240	1,320	1,410	1,490	1,550			
26								1,060	1,160	1,250	1,330	1,410	1,500	1,590	1,660			
27								1,140	1,240	1,330	1,420	1,510	1,610	1,700	1,780	1,870	1,950	1
28									1,320	1,420	1,520	1,610	1,710	1,810	1,900	1,990	2,060	1
29									1,400	1,500	1,610	1,710	1,820	1,920	2,010	2,100	2,180	
30									1,480	1,590	1,700	1,810	1,930	2,040	2,130	2,220	2,300	
31									1,560	1,680	1,800	1,920	2,040	2,160	2,250	2,340	2,430	
32									1,650	1,770	1,910	2,040	2,160	2,270	2,380	2,480	2,570	
Basis (trees)	4	14	20	46	64	80	88	81	74	58	38	24	2		1			594

One-eighth-inch saw kerf, 1-inch boards. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1 foot. Trees scaled in 16-foot log lengths with 0.25-foot trimming allowance and additional top section to 5-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from baisc data, −0.25 per cent. Average deviation of individual tree volumes from tabular values, 11.1 per cent.

TABLE 54.—*Board-foot volume table (international rule), for second-growth western larch*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet																	Basis (trees)
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	
7	6	10	14	19	24	29	35	40										8
8	11	18	25	32	40	48	56	64										24
9	18	28	38	48	58	69	79	89	100									22
10		38	53	66	79	92	105	115	130	145	155							11
11		51	68	85	100	115	135	150	165	180	195	210	220					32
12			86	105	125	145	165	180	200	220	240	255	275					22
13			105	130	150	175	195	215	240	260	285	305	330					22
14			125	150	180	205	230	255	280	305	330	360	390					28
15			145	175	205	240	270	300	330	355	385	415	450					13
16				200	235	275	305	340	375	410	440	475	510	545	580	610		17
17						315	350	385	425	460	500	535	575	615	655	690		18
18						355	395	435	480	520	560	600	640	690	730	770		15
19						395	440	485	530	580	625	670	715	770	815	850		10
20						440	490	540	590	640	690	740	785	840	890	930		14
21							545	595	655	710	760	810	865	925	980	1,020		15
22							595	655	715	775	835	890	945	1,010	1,070	1,120		11
23							650	715	780	845	905	960	1,020	1,090	1,150	1,210		3
24							710	770	840	910	975	1,040	1,110	1,180	1,240	1,300		2
25								830	910	980	1,050	1,120	1,190	1,270	1,340	1,400		5
26								890	980	1,050	1,130	1,200	1,280	1,350	1,430	1,500	1,560	5
27								955	1,050	1,130	1,210	1,290	1,370	1,450	1,520	1,590	1,650	4
28								1,020	1,110	1,200	1,290	1,370	1,450	1,540	1,620	1,690	1,750	1
29								1,080	1,180	1,280	1,370	1,460	1,540	1,630	1,710	1,790	1,850	2
30								1,150	1,260	1,360	1,450	1,540	1,630	1,720	1,810	1,890	1,960	
31									1,340	1,440	1,530	1,630	1,720	1,810	1,900	1,980	2,060	
32									1,420	1,520	1,620	1,720	1,820	1,910	2,000	2,080	2,160	1
Basis (trees)		2	11	17	22	28	33	43	24	37	32	35	17	2	2			305

One-eighth-inch saw kerf, 1-inch boards. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected throughout the western white-pine region in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths, with 0.3-foot trimming allowance and additional top section to 5-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.39 per cent. Average deviation of individual tree volumes from tabular values, 12.2 per cent.

TABLE 55.—*Board-foot volume table (international rule) for second-growth western hemlock*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet														Basis (trees)
	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
7	7	11	15	20	25	31									1
8	10	17	24	32	40	48									1
9		25	35	45	56	68	80	92							3
10		33	46	60	74	89	105	120							2
11			59	76	95	115	135	150							1
12			74	95	115	140	165	185							2
13			90	115	140	170	195	220	245						2
14			110	140	170	200	230	260	295	330					4
15			130	165	200	235	275	310	345	385					6
16			145	190	230	275	315	360	400	445	485	525	565		11
17			165	215	265	310	360	410	455	505	550	600	650		5
18			190	245	300	355	410	465	515	570	625	680	740		5
19			210	275	335	400	460	525	580	640	700	765	830		7
20					370	445	515	585	650	720	790	860	930		3
21					415	495	575	655	725	800	880	960	1,040	1,120	6
22					455	550	640	725	805	885	970	1,060	1,150	1,240	
23					505	605	700	795	885	975	1,070	1,170	1,270	1,360	2
24							770	870	970	1,070	1,170	1,280	1,390	1,490	1
25							840	950	1,060	1,170	1,280	1,390	1,510	1,620	
26							915	1,040	1,150	1,270	1,390	1,510	1,640	1,760	1
27										1,380	1,510	1,640	1,770	1,910	
28										1,490	1,630	1,770	1,910	2,060	
29										1,600	1,750	1,900	2,050	2,210	
30										1,720	1,880	2,040	2,200	2,380	
Basis (trees)			4	3	3	3	13	8	14	9	5	1			63

One-eighth inch saw kerf, 1-inch boards. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected principally on the Coeur d'Alene and Kaniksu National Forests in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths, with 0.3-foot trimming allowance and additional top section to 5-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.44 per cent. Average deviation of individual tree volumes from tabular values, 10.3 per cent.

TABLE 56.—*Board-foot volume table (international rule) for second-growth lowland white fir*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet																Basis (trees)
	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	
7	4	10	16	23	30	36	44										4
8	9	18	28	37	47	57	69	75	83								7
9	15	27	40	53	66	79	92	105	115								8
10		37	54	70	86	100	120	135	150								10
11			68	89	110	130	150	170	185								13
12				110	135	155	180	205	230								4
13				130	160	190	220	250	275	300	330	360					6
14				155	190	220	260	290	320	355	390	425					2
15				180	220	260	300	340	375	415	455	490					9
16					255	300	345	390	430	475	520	565					4
17					290	340	390	440	490	540	590	640	699				6
18					325	385	440	500	555	615	670	725	780				8
19							495	560	620	685	750	810	870	940			7
20							550	620	690	765	835	900	970	1,050			4
21							610	685	760	840	920	990	1,070	1,150			6
22							665	750	830	920	1,000	1,090	1,170	1,260			5
23							720	815	900	995	1,090	1,180	1,270	1,360	1,450	1,540	5
24							770	870	970	1,070	1,170	1,260	1,360	1,450	1,550	1,650	1
25							820	930	1,030	1,140	1,240	1,350	1,450	1,550	1,650	1,750	2
26									1,090	1,210	1,320	1,430	1,540	1,640	1,750	1,850	1
27									1,150	1,280	1,390	1,500	1,620	1,730	1,840	1,950	1
28									1,200	1,340	1,460	1,580	1,700	1,820	1,940	2,050	
29									1,250	1,400	1,520	1,640	1,770	1,900	2,020	2,140	
30									1,300	1,450	1,570	1,700	1,830	1,970	2,100	2,220	
Basis (trees)		2	2	8	9	12	18	17	9	16	13	3	1				113

One-eighth inch saw kerf, 1-inch boards. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected principally on the Coeur d'Alene and Kaniksu National Forests in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance and additional top section to 5-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, −0.59 per cent. Average deviation of individual tree volumes from tabular values, 13.6 per cent.

TABLE 57.—*Board-foot volume table (international rule) for second-growth Douglas fir*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet																Basis (trees)
	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	
7	1	8	14	20	25	30	36										18
8	9	16	24	32	39	48	56	63	69								46
9		24	34	45	56	66	77	86	94								30
10		33	46	59	73	86	100	110	125								19
11			57	74	90	110	125	140	155	170	185						37
12			69	90	110	130	150	165	185	205	225						25
13			84	105	130	155	180	200	220	245	265						23
14			100	125	155	180	205	235	260	285	310						26
15			115	150	180	210	240	270	300	330	360						21
16				170	205	240	275	310	345	380	410	445	480	515			12
17					230	275	315	350	385	425	465	505	545	585			11
18					260	305	350	395	435	485	525	565	610	655			8
19						340	390	440	485	535	580	630	675	725			9
20						380	435	490	540	595	645	695	750	805			5
21						420	480	540	595	655	710	765	820	885			9
22						460	525	590	655	720	780	840	900	970			2
23						500	575	645	715	785	850	915	985	1,060			4
24						545	625	700	770	850	920	995	1,070	1,150			3
25						590	675	755	830	920	995	1,070	1,150	1,240			1
26						635	725	815	895	985	1,070	1,160	1,250	1,340			1
27						680	780	870	960	1,060	1,150	1,240	1,340	1,430			
28						730	835	940	1,030	1,140	1,240	1,340	1,440	1,540	1,640	1,740	
29							890	1,000	1,100	1,210	1,320	1,430	1,540	1,640	1,740	1,850	
30							950	1,070	1,180	1,300	1,410	1,520	1,640	1,750	1,860	1,980	1
31								1,130	1,250	1,380	1,500	1,620	1,750	1,860	1,980	2,100	
32								1,200	1,330	1,460	1,590	1,720	1,850	1,980	2,110	2,240	
Basis (trees)		5	20	27	50	58	61	48	28	9	2	2	1				311

One eighth-inch saw kerf, 1-inch boards. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths, with 0.3-foot trimming allowance, and additional top section to 5-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, less than 0.5 per cent. Average deviation of individual tree volumes from tabular values, 15.4 per cent.

TABLE 58.—*Board-foot volume table (international rule) for second-growth western red cedar*

Diameter breast high (inches)	Volume (board feet) by total height of trees in feet														Basis (trees)
	30	40	50	60	70	80	90	100	110	120	130	140	150	160	
7	9	14	19	24	29	33									3
8	14	20	27	34	42	49	56	63							4
9	19	28	37	47	57	66	76	86							13
10	24	36	48	60	73	86	98	110							10
11		44	58	74	90	105	120	135	150						12
12		53	72	91	110	130	150	170	185	205	220				27
13		62	85	110	130	155	175	200	220	240	260				23
14			100	125	155	180	205	230	250	275	300				20
15			115	145	180	210	240	265	290	315	340				19
16			135	170	205	240	270	300	325	355	385				17
17			150	190	230	270	305	340	370	400	430				11
18			170	210	255	300	335	375	405	440	475				11
19			185	235	280	330	370	410	450	485	525				3
20					310	360	405	450	490	530	575				3
21					340	390	440	490	535	580	625				2
22							480	535	580	630	675	725			3
23							520	575	625	680	730	780			3
24							560	615	670	730	785	840	890	940	1
25							600	660	720	780	840	900	950	1,000	
26							640	700	770	840	900	960	1,020	1,070	
27							680	750	820	890	955	1,020	1,080	1,130	
28							725	800	870	940	1,010	1,080	1,140	1,200	1
29							765	845	920	1,000	1,070	1,130	1,200	1,260	1
30							810	900	970	1,050	1,120	1,190	1,260	1,330	
Basis (trees)		1	11	12	37	54	41	21	7	2	1				187

One eighth-inch saw kerf, 1-inch boards. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance and additional top section to 5-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, less than 1.0 per cent. Average deviation of individual tree volumes from tabular values, 11.9 per cent.

TABLE 59.—*Board-foot volume table (international rule) for second-growth western white pine*

Diameter breast high (inches)	Volume (board feet) by total number of 16-foot logs										Basis (trees)
	1¼	2	3	4	5	6	7	8	9	10	
7	23	35	55	80	100						51
8	25	42	70	97	120						63
9	28	48	82	115	145	180					56
10	30	55	96	135	175	215					46
11	32	62	110	155	200	250					55
12	35	69	125	180	235	290	340				59
13	37	76	140	205	265	330	385				51
14	40	83	160	230	300	370	430	490			46
15	43	91	175	255	335	415	480	550			40
16				285	375	460	540	615	690	765	33
17				315	410	510	600	685	770	850	31
18				345	450	560	660	755	855	950	10
19				380	495	610	725	830	940	1,050	17
20				410	540	665	790	910	1,030	1,150	4
21				445	585	720	855	1,000	1,130	1,260	12
22				480	635	780	930	1,090	1,240	1,380	10
23				520	680	840	1,010	1,180	1,340	1,500	5
24				555	730	905	1,090	1,280	1,450	1,620	3
25				595	780	980	1,170	1,380	1,560	1,750	
26				635	835	1,050	1,260	1,480	1,680	1,880	
27				675	890	1,130	1,350	1,590	1,800	2,020	1
28				715	955	1,210	1,450	1,700	1,920	2,160	1
29				760	1,020	1,290	1,550	1,810	2,040	2,300	
30				805	1,090	1,380	1,650	1,930	2,170	2,440	
31				855	1,170	1,460	1,750	2,040	2,310	2,580	
32				900	1,250	1,550	1,860	2,160	2,440	2,720	
Basis (trees)	25	63	93	106	140	86	63	18			594

One-eighth-inch saw kerf, 1-inch boards. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1 foot. Trees scaled in 16-foot log lengths, with 0.25-foot trimming allowance and additional top section to 5-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, 0.11 per cent. Average deviation of individual tree volumes from tabular values, 8.5 per cent.

TABLE 60.—*Board-foot volume table (international rule) for second-growth western larch*

Diameter breast high (inches)	Volume (board feet) by total number of 16-foot logs										Basis (trees)
	1¼	2	3	4	5	6	7	8	9	10	
7	20	33	50	73							6
8	21	37	60	84	105						24
9	23	41	70	99	125						22
10	25	46	80	115	145	180	205				11
11	27	51	93	130	170	205	240				32
12	30	57	105	150	195	235	275				22
13	32	64	120	170	220	270	315	365			22
14		70	135	190	250	305	360	415			28
15		77	150	215	280	340	400	465			13
16		85	165	235	310	380	450	520	580	645	17
17		92	180	260	345	425	500	575	645	720	18
18		100	195	285	375	465	550	640	715	800	15
19			210	310	410	510	605	700	790	885	10
20			230	335	445	555	660	760	865	970	14
21				365	485	605	715	830	945	1,060	15
22				395	525	655	775	900	1,020	1,150	11
23				430	565	705	840	980	1,110	1,240	3
24				460	610	760	905	1,060	1,200	1,340	2
25				495	650	820	975	1,140	1,290	1,440	5
26				530	700	880	1,050	1,220	1,380	1,540	5
27				565	750	940	1,120	1,310	1,480	1,640	4
28				605	800	1,010	1,200	1,400	1,570	1,750	1
29				640	850	1,070	1,280	1,480	1,670	1,860	2
30				680	905	1,140	1,360	1,580	1,770	1,980	
31				715	960	1,210	1,440	1,670	1,870	2,090	
32				755	1,020	1,280	1,520	1,760	1,970	2,220	1
Basis (trees)	9	25	31	42	45	54	51	42	4		303

One-eighth-inch saw kerf. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths, with 0.3-foot trimming allowance and additional top section to 5-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, 0.23 per cent. Average deviation of individual tree volumes from tabular values, 8.6 per cent.

TABLE 61.—*Board-foot volume table (international rule) for second-growth western hemlock*

Diameter breast high (inches)	Volume (board feet) by total number of 16-foot logs								Basis (trees)
	1¼	2	3	4	5	6	7	8	
7	22	38							1
8	24	43	75						1
9	27	50	87	120	155				3
10	29	56	100	140	185				2
11	32	63	115	165	220				1
12	34	71	130	190	250	320			2
13	37	79	150	220	290	365			2
14	40	87	165	250	325	410	485		4
15	43	96	185	275	365	460	540		6
16	46	105	205	310	405	515	600	705	11
17	49	115	230	340	450	570	670	780	5
18	52	125	250	375	500	625	745	860	5
19		135	275	410	550	690	820	950	7
20		150	300	450	600	750	900	1,040	3
21		160	325	490	655	820	980	1,140	6
22		170	350	530	710	890	1,070	1,240	
23			380	575	770	960	1,150	1,350	2
24			410	620	830	1,040	1,240	1,460	1
25			440	670	890	1,120	1,335	1,570	
26				715	960	1,200	1,435	1,690	1
27				765	1,030	1,290	1,535	1,800	
28				815	1,100	1,380	1,645	1,920	
29				870	1,170	1,475	1,760	2,050	
30				925	1,250	1,575	1,885	2,200	
Basis (trees)	2	5	6	18	16	13	3		63

One-eighth-inch saw kerf, 1-inch boards. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected principally on the Coeur d'Alene and Kaniksu National Forests in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3 foot trimming allowance and additional top section to 5-inch top diameter (inside bark). Table preparedby alignment chart method, 1927. Aggregate deviation from basic data, 0.11 per cent. Average deviation of individual tree volumes from tabular values, 7.9 per cent.

TABLE 62.—*Board-foot volume table (international rule) second-growth lowland white fir*

Diameter breast high (inches)	Volume (board feet) by total number of 16-foot logs								Basis (trees)
	1¼	2	3	4	5	6	7	8	
7	22	38	62	86					3
8	24	43	72	100	130				7
9	26	49	84	120	155				8
10	28	55	98	140	185				10
11	31	62	115	165	215	265			13
12	34	69	130	190	250	305			4
13	37	77	150	215	280	350			6
14	40	85	165	245	320	395	465		2
15		94	185	275	360	445	525		9
16		105	205	305	400	495	585	680	4
17		115	225	335	440	545	650	750	6
18		125	250	365	485	605	720	830	8
19		135	270	400	530	660	790	920	7
20		145	295	435	580	725	865	1,000	4
21			320	475	630	785	940	1,090	6
22			345	510	680	850	1,020	1,180	5
23			370	555	735	920	1,100	1,280	3
24			400	595	795	990	1,185	1,380	3
25			430	640	855	1,070	1,270	1,480	2
26					915	1,150	1,360	1,580	1
27					980	1,230	1,450	1,690	1
28					1,050	1,310	1,550	1,790	
29					1,120	1,390	1,650	1,900	
30					1,190	1,480	1,750	2,010	
Basis (trees)	3	13	18	18	17	21	17	5	112

One-eighth-inch saw kerf, 1-inch boards. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected principally on the Coeur d'Alene and Kaniksu National Forests in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3 foot trimming allowance and additional top section to 5-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, 0.72 per cent. Average deviation of individual tree volumes from tabular values, 8 per cent.

TABLE 63.—*Board-foot volume table (international rule) for second-growth Douglas fir*

Diameter breast high (inches)	Volume (board feet) by total number of 16-foot logs								Basis (trees)
	1¼	2	3	4	5	6	7	8	
7	19	33	55	75					18
8	20	37	62	89	110				46
9	22	41	71	105	130				30
10	25	45	83	120	155				19
11	28	51	95	140	180	220			37
12	30	58	110	160	205	250			25
13	32	66	120	180	235	285	340	390	23
14	35	73	135	205	265	325	385	440	26
15	37	80	155	230	300	370	435	505	21
16		88	170	250	330	410	485	570	12
17		96	185	275	370	460	540	635	11
18		105	205	305	405	510	600	705	8
19		115	225	330	445	560	665	775	9
20		125	245	360	485	610	725	850	5
21			265	395	530	670	790	930	9
22			285	430	575	725	865	1,020	2
23			310	470	620	785	940	1,100	4
24			330	505	670	850	1,010	1,190	3
25			360	545	725	920	1,090	1,280	1
26			385	585	780	985	1,170	1,370	1
27			415	625	835	1,050	1,260	1,470	
28			445	670	890	1,130	1,340	1,570	
29			475	710	950	1,200	1,430	1,680	
30			510	760	1,010	1,280	1,530	1,790	1
31			540	800	1,080	1,360	1,620	1,900	
32			570	850	1,140	1,450	1,720	2,010	
Basis (trees)	25	65	60	74	72	12	2	1	311

One-eighth-inch saw kerf, 1-inch boards. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance, and additional top section to 5-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, 0.89 per cent. Average deviation of individual tree volumes from tabular values, 9.7 per cent.

TABLE 64.—*Board-foot volume table (international rule) for second-growth western red cedar*

Diameter breast high (inches)	Volume (board feet) by total number of 16-foot logs						Basis (trees)
	1¼	2	3	4	5	6	
7	21	34	57				3
8	23	39	65				4
9	25	44	75	105			13
10	27	50	86	125			10
11	29	56	98	140	180		12
12	31	62	115	165	210	250	27
13	34	68	130	185	235	285	23
14	36	75	140	205	265	320	20
15	38	82	155	225	295	355	19
16	41	90	175	250	325	395	17
17	43	98	190	275	355	435	11
18	46	105	210	300	390	475	11
19	48	115	225	325	425	520	3
20	51	125	245	350	460	560	3
21		135	265	380	500	610	2
22		145	285	410	535	655	3
23			305	440	575	705	3
24			325	475	615	760	1
25			345	505	655	815	
26			370	540	700	875	
27			395	575	745	935	
28			420	610	790	1,000	1
29			445	645	840	1,070	1
30			475	680	890	1,140	
Basis (trees)	4	23	59	71	27	3	187

One-eighth-inch saw kerf, 1-inch boards. For ¼-inch kerf deduct 9.5 per cent. Block indicates extent of basic data. Data collected throughout the western white pine region in stands from 30 to 160 years of age. Stump heights, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance and additional top section to 5-inch top diameter (inside bark). Table prepared by alignment-chart method, 1927. Aggregate deviation from basic data, 0.17 per cent. Average deviation of individual tree volumes from tabular values, 8.3 per cent.

APPENDIX

YIELD-TABLE MATERIAL AND TECHNIC

TABULAR BASIS

The field and office methods used in this study were essentially those outlined by a committee of the Society of American Foresters (*2*). The basic data consist of 306 sample plots, collected in a systematic search of a large number of western white pine stands between 20 and 160 years of age. The general distribution of these plots by locality is shown in Figure 1. All plots were located in essentially even-aged, normal stands judged to be producing maximum volume for their particular age-site condition. That normal stocking can be recognized with reasonable accuracy is shown by the fact that three collectors, F. I. Rockwell, A. O. Benson, and the writer, working at widely separated intervals, chose for study stands with densities not greatly dissimilar.[4]

PLOT MEASUREMENTS

Plot boundaries were surveyed with a staff compass and steel tape. Horizontal measure was used throughout. The nature of the stands made it impracticable to obtain strictly rectangular plots, but plots were usually 4-sided and acute angles were avoided. The age of the stand represented by each plot was determined by annual-ring counts on increment cores taken from several dominant and codominant white pines, these counts being adjusted to allow for the time needed for a dominant seedling to grow to the height above ground at which the boring was made. Occasionally an intermediate or suppressed tree was bored to make sure that the stand was essentially even-aged; i. e., that the ages of the youngest and oldest trees did not vary by more than 20 years.

Height over diameter curves were prepared for each species present, except that quite frequently the curves of subordinate species present in minor amounts were used on several plots in the same vicinity. A tally of trees by diameter, species, and crown class and a general plot description completed the field work. The volumes for all plots were computed by means of the second-growth volume tables presented in this bulletin, the plots collected in previous studies being recomputed in this way.

The methods used in 1909–1912 varied somewhat from those just described. Most of these variations were of minor importance; but one omission, the lack of a tally by crown class, necessitated an indirect method of site classification for the older plots. Fortunately, this proved an easy matter, due to the definite relation existing between the average diameter of all white pines and the average diameter of the dominant white pines.[5] As the average diameter of all white pines present was easily computed, the size of the average dominant could be determined in turn from this relation and the corresponding height needed in site classification read from the white pine height curve for the plot. This method of site classification was checked on plots for which the actual average dominant height had been measured. About one-half of the predicted values were within 2 feet and two-thirds within 3 feet of the value derived in the usual manner.

SEEDLING HEIGHT GROWTH

As a knowledge of seedling height growth is essential to accurate age determinations, an analysis was made of the growth of 275 dominant white-pine seedlings scattered over a variety of sites and aspects. These measurements show that on soil of average fertility dominant white pines require about 5 years to reach 1 foot and 11 years to reach 4.5 feet in height. The range of sites sampled in this seedling analysis (site index 55 to 65) does not permit accurate adjustment of these values on the basis of side-index classes, though undoubtedly average rate of

[4] The stand density of the plots taken by each collector was expressed in basal area and compared with the average basal area of the plots of all collectors combined. F. I. Rockwell's plots averaged 4 per cent higher, A. O. Benson's 6 per cent lower, and the writer's 0.5 per cent higher than the average.

[5] This relation was first suggested in the case of Douglas fir by R. E. McArdle, Pacific Northwest Forest Experiment Station.

growth varies measurably with site conditions. However, this variation is rather immaterial at 1 foot, for on the best site sampled it required 4 years and on the poorest site only 6 years for dominants to reach a 1-foot height. On this basis, age determinations in western white pine stands based on annual-ring counts 1 foot above the average ground level can be converted to total age with reasonable accuracy by adding 5 years on average soils, 4 years on better-than-average soils, and 6 years on poorer-than-average soils.

Adjustment of ring counts taken at breast height can be made only with a decrease in accuracy, as the effect of site differences on seedling growth is more noticeable by the time breast height has been reached. For this reason all age counts are made at 1 foot above ground level, or, if the large size of dominants or some similar reason makes this inconvenient, the ring count is converted to age at the 1-foot level by adding the number of branch whorls or knots between breast height and the 1-foot level. When it was necessary to convert breast-high counts to total age at ground, 11 years were added on average sites, 9 years on better-than-average sites, and 14 years on poorer-than-average sites.

PLOT REJECTION

The usual difficulties of locating and recognizing normal stands in the field, and the consequent need of some flexibility in selection to assure reasonable progress, made it desirable to examine data from all plots in the office for possible abnormalities in stocking. Basal-area and number-of-tree deviations of individual plots from the corresponding average values read from a preliminary table were used as the criteria in this work. Each tabular value was, of course, properly interpolated for age and site. These deviations were expressed as percentages of average or tabular values, and any plot varying by more than 2.5 times the average deviation of all plots (i. e., approximately twice the standard deviation) was tentatively rejected. Because of a definite plus skewness in the frequency distribution of these data—i. e., the occurrence of more plots denser than the average than plots less dense—the plus and minus deviation groups were treated separately to assure a more equitable rejection (*13*). This plus skewness is recognizable in each collector's group alike and is undoubtedly due to the relative ease with which understocked plots are recognized and rejected in the field as compared with overstocked. In plot rejection, therefore, the average plus deviation was used with plots denser than average and the average minus deviation with plots less dense. Plot rejection was not purely mechanical; each plot tentatively discarded was carefully scrutinized before a final decision was made as to retention or rejection. The use of both basal area and number of trees in this work set rather high standards, however, and altogether 35, or 11.4 per cent, of the plots were rejected. Of this total, 52 per cent were rejected on basal area, 34 per cent on number of trees, and 14 per cent because of abnormalities in both criteria. Practically all of the remaining plots were within +34 or −30 per cent by basal area and within +73 or −60 per cent by number of trees.

PLOT DISTRIBUTION

The yield tables are based on the remaining 271 plots. These plots vary in size from about 0.05 acre to 2 acres in area, about 60 per cent being under one-half acre and 85 per cent under 1 acre. Each plot was so chosen as to contain a good sample of trees adequately covering their range and distribution in size. Usually 100 to 300 trees per plot was considered an adequate sample.

Table 65 shows plot distribution by age and site class. Note that while the plots are fairly well distributed by age, they are heavily concentrated in a few site-index groups. As particular stress was laid in this study on the desirability of measuring yields on very good and very poor soils, as well as under average conditions, this concentration strongly indicates that, although the range in site quality throughout the western white pine type is large, some 70 per cent of the land producing pine is in two site-index classes and almost 90 per cent in three such classes. An examination of the tabular yields will show the very large differences in wood-producing capacity between the major site groups.

TABLE 65.—*Distribution of normal plots by age and site class*

Age class (years)	Distribution (number) by site index (feet)								
	20–29 feet	30–39 feet	40–49 feet	50–59 feet	60–69 feet	70–79 feet	80–89 feet	All plots	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Per cent*
20–29				1	1			2	1
30–39	3	9	10	2	2	2		28	10
40–49		1	3	8	14	7	3	36	13
50–59		1	4	11	16	1	1	34	12
60–69			1	4	4			9	3
70–79			3	8	2			13	5
80–89			7	7	4			18	7
90–99			2	4	8	1		15	6
100–109			2	13	29	4		48	18
110–119		1	3	9	12			25	9
120–129				5	5			10	4
130–139				4	2			6	2
140–149			2	5	7			14	5
150–159				8	5			13	5
Total	3	12	37	89	111	15	4	271	
Percentages	1	4	14	33	41	6	1		100

Table 66 gives the distribution of plots by situation and aspect. The preference of western white pine for moist, protected slopes is indicated in this table, since almost half of the classified plots are located on lower northerly aspects. A preliminary analysis of these data with regard to site conditions fails to show any relationship between site quality, situation, and aspect. This is contrary to the usual assumption that lower slopes, for example, are distinctly better in site quality than the ridges, and north slopes similarly better than south slopes. The yield-study data, while too inadequate to solve this problem, indicate that such assumptions on a region-wide scale are at present unwarranted. It will require a great deal of careful investigation to solve this problem and determine to what extent the more favorable moisture relationships on north aspects are compensated on south slopes by a longer growing season, a longer sunlight day, and higher soil and air temperatures.

TABLE 66.—*Distribution of normal plots by aspect and situation*

Aspect	Situation					All plots	
	Flat	Lower slope	Middle slope	Upper slope and ridge	Unclassified		
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Per cent*
Northwest		10	9	6	3	28	11
North		38	13	22	3	76	28
Northeast		18	10	5	3	36	13
East		10	2	2	6	20	7
Southeast		8	1	6	1	16	6
South		4	4	5		13	5
Southwest		5	1	6	1	13	5
West		13	1	3		17	6
None	32					32	12
Unclassified		1		7	12	20	7
Total	32	107	41	62	29	271	
Per cent	12	39	15	23	11		100

CONSTRUCTION OF YIELD TABLES

Yield-table construction followed the methods outlined by Reineke (*15*). Briefly, in this method the tables are based on a series of average curves showing the trend of average dominant height, total stand basal area, average tree basal area, and cubic-foot volume over age. In this study all plots between 45 and 69 feet in site index were used in drawing these average or graduating curves. The usual series of conventional curves are easily derived from these average curves, as the values of any such curves at any age can be expressed as percentages of the average curve value at that age.

The chief advantage of this method is that the tables are based primarily on a series of strong, well-defined curves. This is particularly true of the alignment-chart method proposed by Reineke, for here only one curve need be fitted for each item instead of a series of curves, one for each site class. This general method also produces a stronger table through a very effective system of interchecking related values. For example, the curves of tree basal area, number of trees, and stand basal area must check one another; i. e., at any age the product of tree basal area and number of trees must equal stand basal area. Furthermore, another check is introduced in the so-called *forest form factor–age* curve. The forest form factor is obtained by dividing the cubic volume by the product of stand basal area and the dominant height used in site classification. This value is used to check the curves for stand basal area, height, and cubic volume, for at any age cubic volume should equal the product of stand basal area, average dominant height, and forest form factor. Finally, the fit of these curves to their basic data was checked by computing the average and aggregate deviations for a number of important values. These deviations are listed in Table 67. The average deviations are based on the deviations of individual plots from tabular values expressed as percentages of tabular value. The great variation of individual plots from the tabular values for stands of the same age and site, particularly in such items as number of trees and board-foot volumes, are shown by the relative size of the average deviations. The aggregate deviation is the difference between the sum of the actual values for all plots and the estimated or tabular values of all plots interpolated for year of age and foot of site index. This difference is expressed as a percentage of the sum of the tabular values. The low aggregate deviations indicate that on the whole the tabular curves are correctly balanced against their basic data. Because of the fundamental simplicity of the methods involved, as well as the careful system of cross checking just described, it is felt that yield tables constructed by the alignment-chart method give the maximum degree of accuracy for the data involved.

TABLE 67.—*Average and aggregate deviations of important yield-table values*

Item	Average deviation	Aggregate deviation
	Per cent	*Per cent*
Basal area	±14.1	−0.04
Number of trees	±27.1	[2]−0.08
Total cubic-foot volume	±17.3	+0.32
Board-foot volume:		
International, trees 7 inches and larger	[1]±22.1	+0.51
Scribner, trees 8 inches and larger	[1]±30.7	+1.33

[1] With 1 very eccentric value omitted.
[2] Based on percentage deviations.

The alignment-chart method also permits the presentation of an entire set of yield tables in extremely condensed form. Figure 12 shows the entire set of 22 yield tables given in this report condensed to a single page. Partial stand values, however, can not be read directly from this chart but must be obtained through converting factors. Instructions for reading this chart are given in Table 68.

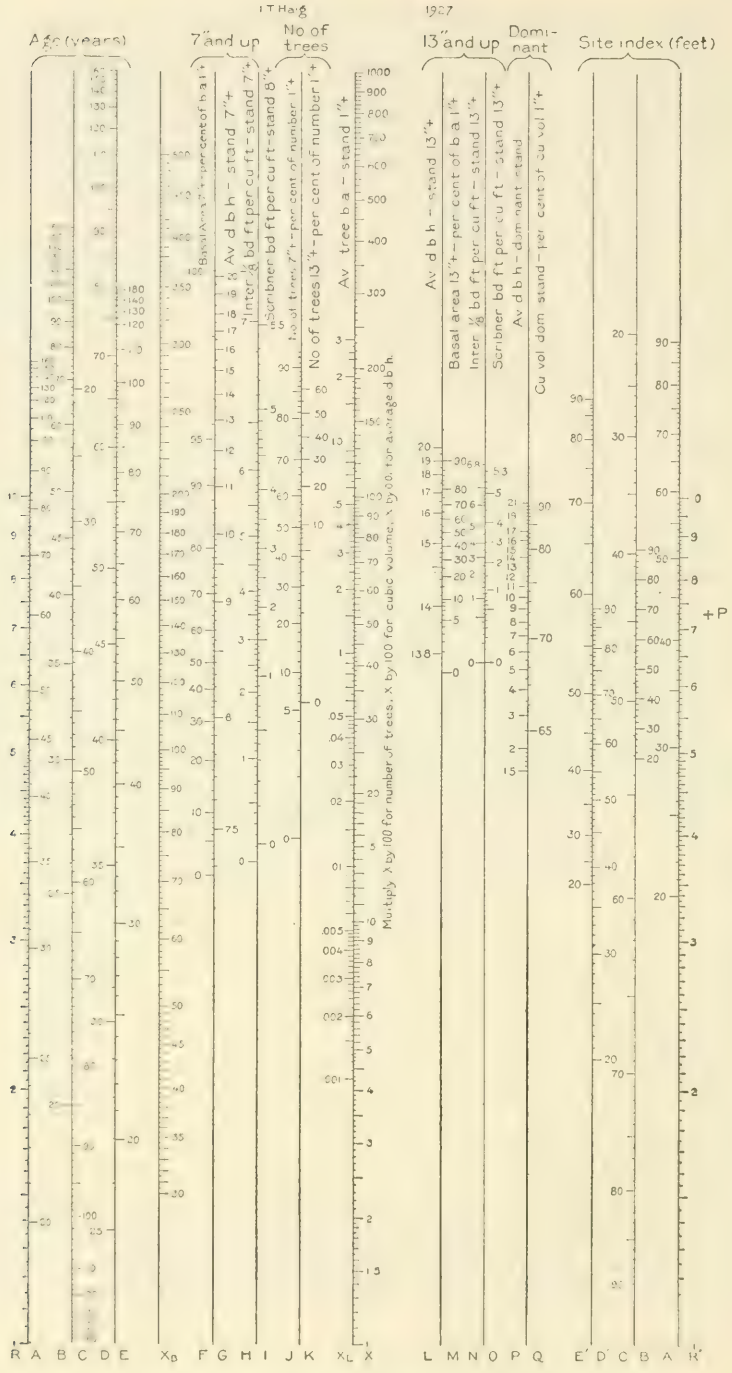
I T Haig
1927
Age (years)
7" and up
No of trees
13" and up
Dominant
Site index (feet)
Av d b h – stand 7"+
Inter ¼ bd ft per cu ft – stand 7"+
Scribner bd ft per cu ft – stand 8"+
No of trees 1"+ – per cent of number 1"+
No of trees 13"+ – per cent of number 1"+
Av tree b a – stand 1"+
Multiply X by 100 for number of trees, X by 100 for cubic volume, X by 0.01 for average d b h.
Av d b h – stand 13"+
Basal area 13"+ – per cent of b a 1"+
Inter ¼ bd ft per cu ft – stand 13"+
Scribner bd ft per cu ft – stand 13"+
Av d b h – dominant stand
Cu vol dom stand – per cent of cu vol 1"+
+P
R A B C D E
Xb
F G H I
J K
XL X
L M N O P Q
E' D' C B A R'

FIGURE 12.—Alignment-chart yield table for second-growth western white pine stands

TABLE 68.—*Instructions for using alignment-chart yield table (fig. 12)*

To obtain—	Hold age on	Hold site index on	Read	Multiply by
A. Site classification, hold age A, hold height of average dominant on X, and read site index on A′.				
B. Height of average dominant white pine	A	A′	X	
C. For entire stand:				
1. Number of trees per acre	C	C′	X	100
2. Average diameter breast high (inches)	E	E′	X	0.1
3. Basal area (square feet per acre)	B	B′	X_B	
4. Volume per acre (cubic feet)	D	D′	X	100
5. Average tree basal area (square feet)	E	E′	X_E	
D. Partial stand: For any of the following items determine similar entire-stand value. Determine average diameter for entire stand. Then pass a straight line through this average diameter on X and point P. Along this line for—				
1. Stand 7 inches and larger—				
Number of trees (per cent)			J	
Average diameter (inches)			G	
Basal area (per cent)			F	
Board feet per cubic foot			H	
2. Stand 8 inches and larger—				
Board feet per cubic foot			I	
3. Stand 13 inches and larger—				
Number of trees (per cent)			K	
Average diameter (inches)			L	
Basal area (per cent)			M	
Board feet, international (¼-inch) rule, per cubic foot			N	
Board feet, Scribner (decimal C) rule, per cubic foot			O	
4. Dominant stand—				
Average diameter (inches)			P	
Cubic-foot volume (per cent)			Q	
E. To convert percentages and ratios to actual values, hold entire stand or total value on R. Hold percentage or ratio on R′. Read partial stand value on X, pointing off as with a slide rule.				

STATISTICAL ANALYSIS OF RESULTS

STAND COMPOSITION AND YIELD

As has been stated, the western white pine type contains an extremely complex and variable mixture of species. Because it seemed quite possible that certain combinations might be able to utilize the site more fully than others and hence produce higher yields, it was necessary to determine the effect of stand composition on yield. Accordingly, a study was made of the extent to which variations in yield of individual plots from the average or tabular values are associated with variations in stand composition. Modern correlation technic (*4*, *7*) offered the best method of handling this complex problem, furnishing both a numerical measure of the degree of association or correlation between yield and stand composition and a method, if such correlations were found to exist, of predicting the size of such deviations, thus permitting proper adjustment of yield-table values on the basis of stand composition.[6]

From this correlation study it can be stated that stand composition does have a definite though ill-defined effect upon timber yield. While no definite division can be made, it is generally true that, on an average, tracts of pure white pine or stands with large amounts of white fir and, to a lesser extent, Douglas fir tend to overrun the average or tabular volumes, while stands containing large amounts of hemlock and, to a lesser extent, larch and cedar tend to run somewhat lower in volume than the average. These tendencies, however, are weak and relatively ill defined, as indicated by the small size of the correlation indices, which are 0.27 ± 0.06 for the board-foot-stand composition and 0.41 ± 0.05 for the basal area-volume stand composition relationships. (Correlation index is a statistical measure of the degree to which two variables—in this case, yield in either board feet or basal area and stand composition—tend to associate or change together.) As the correlation indices show, the relation between basal-area values, and hence probably cubic-volume yields and stand composition, is somewhat stronger than the relation between board-foot volumes and composition. Nevertheless,

[6] The formula used was: Volume (actual in percentage of tabular volume) = stand composition by basal area (i. e., sum of the percentages of white pine, western larch, Douglas fir, lowland white fir, western hemlock, western red cedar, and miscellaneous).

in neither case is the correlation strong enough to permit the accurate prediction, for any given stand composition, of the corresponding percentage of overrun or underrun from tabular values.

Stand composition is simply one of a number of factors, though one peculiar to mixed stands, causing variation in yield about the average. As over 90 per cent of the total variation is caused by factors other than stand composition, the effect of this factor is largely obscured by other variables and can, for most practical purposes, be ignored. Indeed, in the method of application suggested, calling for a cruise of the stands for which yields are to be predicted, the effect of stand composition on yield, up to the age of the stands sampled, has already made its influence felt and is properly allowed for in the measured basal-area values. The effect of stand composition on future growth, however, can not be predicted accurately on the basis of our present knowledge and, as with deviations in degree of stocking, must be ignored in making future predictions. In general it should be noted that in stands containing large amounts of western white pine, white fir, and to a lesser extent Douglas fir, overstocking as commonly defined in terms of basal-area values may be at least partially due to the effect of stand composition as well as to abnormal density. To this extent such stands may always remain somewhat higher yielding than the average stands. In like manner stands containing large amounts of hemlock, and to a lesser extent larch and cedar, may be somewhat lower yielding than the average, partially or entirely because of the effects of stand composition as well as any lack of adequate numbers of trees or their proper distribution. In this case and to the extent to which this is true, no progress toward normality can be expected and such stands may always remain somewhat lower yielding than the average.

Under the method of application suggested, in which the present relation of actual stand volumes and tabular volumes is held to remain the same at the future age for which yield predictions are desired, stand composition will tend to result in somewhat conservative predictions for all of the higher yielding combinations, such as white pine-white fir mixtures, and will not result in any appreciable error for stands containing large quantities of hemlock or other species forming the less rapidly growing combinations. In some cases, when predictions are made in the suggested manner, stand composition will tend to counterbalance the tendency of stands to grow toward normality and thus tend to result in more accurate predictions, though in understocked stands of desirable composition the converse will be true.

COMPOSITION AND SITE INDEX

Not only do certain species and combinations of species seem to be able to utilize a given site more efficiently than other species or combinations, and hence produce higher yields, but in addition certain species and mixtures of species seem to be, on the whole, higher yielding than others simply because they tend to occupy the better sites. This is illustrated in the case of pure white pine stands, which on an average are found on the better, higher-yielding sites.

As a knowledge of this relation would be of considerable interest and possibly of value, a study was made of the correlation existing between site and stand composition. If stand composition is expressed in terms of individual species, the multiple correlation coefficient of this relation is 0.35 ± 0.05. This coefficient, showing a weak relation between site and stand composition, would undoubtedly be materially higher if curvilinear relations were considered. If stand composition is expressed in percentage of white pine and curvilinear relations are measured, the correlation index is $+0.66 \pm 0.03$, showing a fairly definite tendency for site index to increase with an increase in percentage of white pine. This coefficient, however, must be regarded with some suspicion, as its size largely depends on the presence of plots from one locality, practically all of which are over 80 per cent white pine and on very good quality soils. It is quite possible that the actual degree of relation is somewhat exaggerated. In conclusion, the best that can be said at this time is that certain mixtures do tend to occur on better or poorer soils than the average and hence run higher or lower in yield than the stand of average composition.

APPLICATION METHODS

As has been stated, the application of normal-yield tables to natural stands requires as one preliminary step the determination of the present density of the stand in terms of normal or tabular stocking. Practical considerations necessitate that stocking be measured in terms of some easily obtained value, such as number of trees or basal area, and that this measure be used to represent degree

of stocking in terms of more important values, such as cubic and board foot volumes. Because of irregularities in tree distribution, tree size, and composition, a stand of a given degree of normality according to one factor may not be normal to the same degree in terms of some other stand factor; for example, a stand 80 per cent normal by basal area may not be 80 per cent normal in board-foot contents. Accordingly, a study was made of the relation existing between various stand factors as measures of stocking to evaluate their use in application work.

The basic data for these studies consisted of 306 yield plots, only 35 of which were above or below the recognized normal limits in total number of trees and basal area. Normal plots proved usable in this work, though undoubtedly some distortion is caused by the fact that all of these plots had practically complete crown canopies. For each plot the actual value was expressed in percentage of the corresponding tabular value interpolated for year of age and foot of site index. The deviation of actual from tabular value was shown, of course, in the extent to which this percentage varied from 100 per cent, the tabular value. A study was then made, by means of the correlation technic previously mentioned, of the manner in which plot variations from the normal in any one item are associated with variations from normal in some other plot factor. The correlation coefficients and related statistical constants derived from this study are given in Table 69. As previously stated, the correlation coefficient is a statistical constant showing the degree of the relation between two variables. Such coefficients are held to be reliable if more than three times the size of their standard deviation. Some relation may be said to exist, therefore, between each set of items listed in Table 69 except between cubic volume and number of trees.

The size of these coefficients is an indirect measure of the strength of the relation; and the closer these values approach 1.0, the coefficient representing perfect correlation, the stronger the relation involved. Cubic volume, for example, may be considered closely related to stand basal area, and a change in basal area above or below normal will be accompanied on an average by a corresponding change in cubic volume. The correlation coefficients for total board foot volume and number of trees 7 inches in diameter and larger and for board foot volume and number of trees 13 inches in diameter and larger, respectively, are also relatively high. For this reason, stand basal area has been recommended as the most accurate, most easily obtained item to be used as a measure of stand normality when cubic-foot volume predictions are desired. Number of trees above a given merchantable diameter limit is probably the best when board-foot volumes are needed. The latter criterion is a particularly attractive one, as it requires only a count of merchantable trees as compared to a tally by diameter class of the entire stand. The use of number of trees above a certain size is only feasible, however, in stands that have reached merchantable size, and in addition can only be recommended for short-time predictions, for nothing is known of the possible effect on this measure of stand progress toward normality. Consequently, in young stands or for long-time predictions, stand basal area is still recommended as the most reliable gage of stocking even when board-foot predictions are desired. Indeed, when the curvilinear trend is allowed for, the correlation index for this relationship becomes $+0.79 \pm 0.02$, indicating a very real relation between the normality of the stand by board foot volume and stand basal area. Some further study is necessary, however, before the exact trend of this relation can be accurately defined. Further work, in fact, is desirable with all of the more important relationships, and this work must be done with a series of plots covering a much wider range of stocking.

TABLE 69.—*Correlation coefficients for various important stand factors*

Between normality percentages of—	Correlation coefficient	Standard deviation of correlation coefficient
Cubic volume—total number of trees	+0.10	±0.06
Cubic volume—stand basal area	+.82	±.02
Board foot, international rule, trees 7 inches and larger and—		
Stand basal area	+.28	±.06
Cubic volume	+.43	±.05
Average tree basal area	+.52	±.04
Number of trees, 7 inches and larger	+.70	±.03
Board foot, international rule, trees 13 inches and larger and number of trees 13 inches and larger	+.88	±.02

STAND-TABLE MATERIAL AND TECHNIC

The method of constructing stand tables used in this study will not be outlined in detail here, since this has already been done elsewhere by Bruce and Reineke (*3*). Briefly, this method utilizes the discovery that in all stands of the same average diameter and similar species, regardless of age and site, tree distribution by size follows very definite and recognizable trends. Occasionally the distribution of tree diameters follows the Gaussian curve of normal frequency distribution (*1*) and can be fairly easily described by mathematical means or plotted in straight-line form upon normal-probability paper. More frequently, however, tree distributions are somewhat skewed and fail to conform to this normal curve. This was found true in western white pine stands in which the curves of tree distribution failed to assume straight-line form on any of the common types of proba-

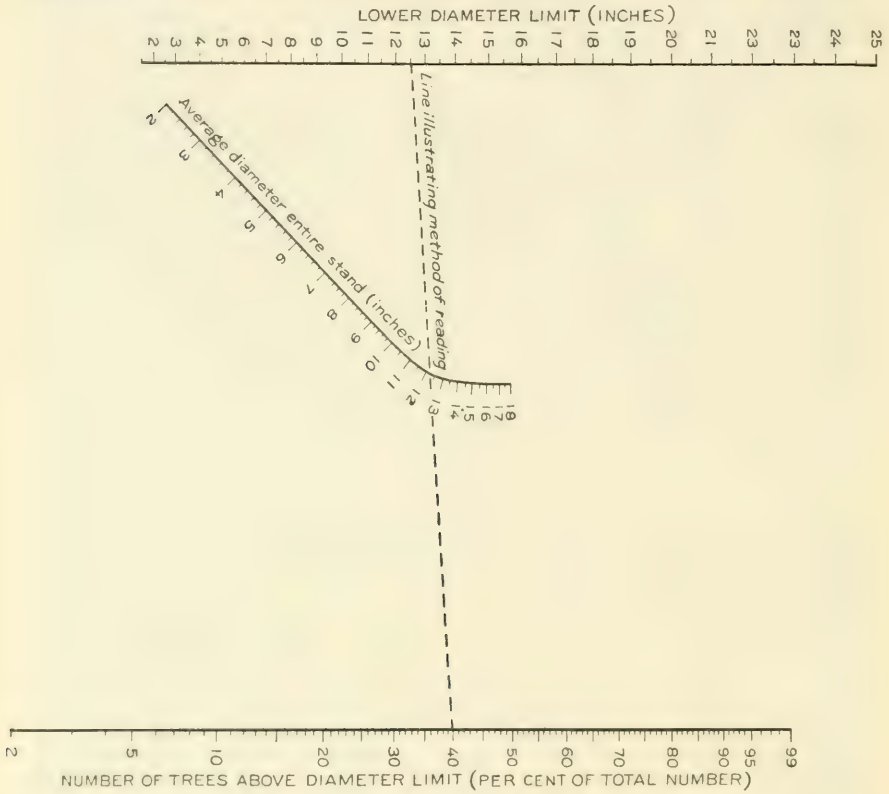
LOWER DIAMETER LIMIT (INCHES)
Average diameter entire stand (inches)
Line illustrating method of reading
NUMBER OF TREES ABOVE DIAMETER LIMIT (PER CENT OF TOTAL NUMBER)

FIGURE 13.—Stand-table chart showing the distribution of trees by diameter class in fully stocked second-growth western white pine stands of average composition

bility paper. The alignment-chart method devised by Bruce and Reineke is, however, effective in many cases of highly skewed types of distributions. Indeed, this method is so flexible that it proved readily possible to express in alignment-chart form not only the complex tree-diameter distributions for mixed western white pine stands but also the even more complex distributions of stand basal area and cubic-foot volume. Only in the expression of the frequency distribution of volumes in board feet, apparently distorted by the rigid lower diameter limit, did the alignment-chart method prove inadequate. It proved quite possible, however, to express board-foot distributions in a somewhat more complex graphic form.

The basic data in all of this work consisted of the normal-yield plots with complete tree tallies to and including the 1-inch class. These plots were grouped into 1-inch classes according to average diameter of the entire stand, and for each

of these groups a curve was prepared showing the accumulative percentage of total number of trees above successive lower diameter limits. This series of curves was in turn reduced to a single composite or graduating curve showing the average accumulative percentage of total number of trees for various lower diameter limits. This curve was then anamorphosed into straight-line form and used in the preparation of an alignment chart (fig. 13), showing for stands of various average diameters the percentage of total number of trees above various lower diameter limits.

To use this chart, pass a straight line through any chosen lower diameter limit on the left-hand scale and the average diameter of the entire stand (based on average tree basal area) on the short-center scale and read the percentage of total number of trees above the chosen diameter limit where this extended straight line crosses the right-hand or percentage scale. If, for example, the stand averages 12.2 inches in diameter at breast height (the average diameter of 120-year-old stands on good sites as shown in the yield tables) and it is desired to know the percentage of trees in and above the 13-inch class, pass a straight line through 12.5, the lower diameter limit of the 13-inch class on the left-hand scale, and 12.2, the average diameter of the entire stand on the center scale, and read 40.0 per cent on the right-hand scale. This reading is illustrated in Figure 13. To convert this percentage reading to actual number of trees, multiply it by the total number of trees in the stand, in this case 390. A series of readings at successive diameter limits, each reading being subtracted in turn from that of the preceding value, will give a series of percentage values of trees in each individual diameter class. These percentages are, of course, easily converted into actual number of trees by multiplying by the total number of trees in the stand.

Similar charts were prepared in the same manner for total stand basal area and total cubic-foot volume. In each case the reliability of these charts has been checked graphically against its basic data and scale adjustments made, until the chart conformed very closely to these data and it was evident that any further improvement would be too slight to warrant the labor involved. The reliability of these charts in practical application as affected by stocking and composition has already been discussed.

VOLUME-TABLE MATERIAL AND TECHNIC

BASIC DATA

The basic data for these tables consist of individual tree measurements collected in second-growth stands throughout the western white pine type by a large number of forest officers. The field methods used in collecting these data were in the main those outlined in the standard methods (*2*). The office computations for western white pine (except the actual preparation of the tables) also conformed quite closely to these standard instructions. But the tree measurements for all other species were plotted on basal-area paper and their volumes computed by the methods described by Reineke (*14*).

METHOD OF CONSTRUCTION

The method of constructing volume tables used in this study has also been outlined elsewhere (*16*). Briefly, it consists in an application of multiple curvilinear correlation principles to volume-table construction. Each volume table is prepared originally in alignment-chart form.[7] The method employed bases the entire table on a few curves fitted to the whole of the basic data. As a result each curve is strongly defined, and the resulting chart gives the best approximation of individual-tree volumes from known heights and diameters that it is possible to make with the material used. In addition, while the technic is somewhat difficult to master at first sight for anyone not mathematically trained, the method is essentially simple. It is very rapid; the basic curves are often straight or approximately straight lines and hence easily fitted with the least possible demand on the judgment of the constructor. The alignment-chart form in which the tables are originally built, illustrated for the white pine cubic-foot volume table in Figure 14, also permits rapid interpolation and checking. To read this chart, pass a straight line between the tree diameter and the total height and read the cubic contents where this line crosses the center scale.

[7] In each case the alignment chart expresses the multiple curvilinear correlation equation: Tree volume = function (tree diameter breast high + tree height).

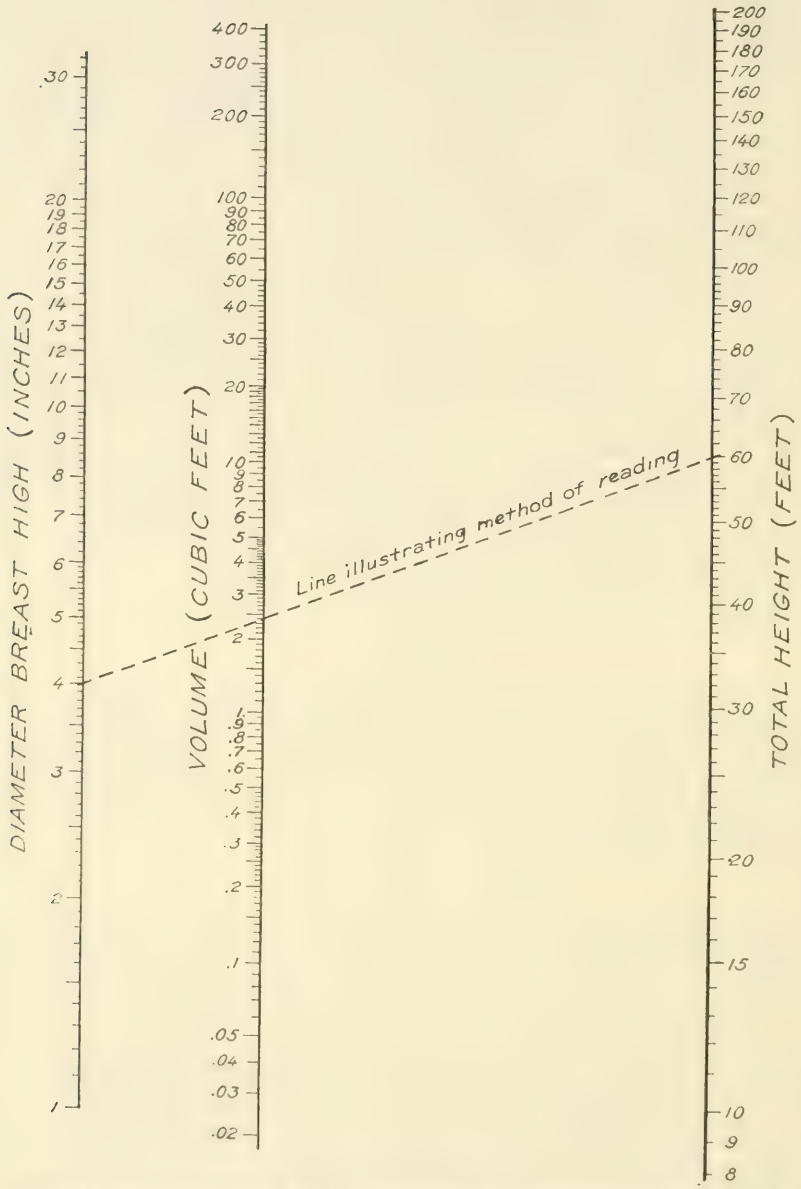

FIGURE 14.—Alignment chart showing cubic-foot volumes for western white pines of various diameters and heights

TABULAR CHECKS

Table 70 shows the aggregate and average deviations for the 30 volume tables presented in this bulletin. The aggregate deviations represent the difference between the sum of the actual volumes of the trees used in preparing the table and the sum of similar volumes read from the table for trees of corresponding diameters and heights. This difference is expressed in percentage of the tabular volumes. These deviations never exceed 1 per cent, and about two-thirds of them are 0.5 per cent or under. These checks are considered very satisfactory. The average deviations are based on the deviations of individual tree volumes from the corresponding tabular volume interpolated to the nearest tenth inch of diameter and foot of height. These deviations are almost all relatively small. The total-height tables, both cubic foot and board foot, were also checked by computing and plotting the board foot–cubic foot ratios and introducing such minor changes in the charts as were necessary to produce reasonable trends in these data when over plotted diameter.

TABLE 70.—*Aggregate and average deviations for second-growth volume tables*

AGGREGATE DEVIATIONS

Species	Type of table				
	Cubic	Scribner		International	
	Total height	Total height	Merchantable height	Total height	Merchantable height
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Western white pine	±0.50	+0.44	−0.13	−0.25	+0.11
Western larch	−.60	+.70	−.25	−.39	+.23
Western hemlock	+.31	−.23	−.06	−.44	+.11
Lowland white fir	+.02	−.18	−.14	−.59	+.72
Douglas fir	−.60	+.70	−1.00	±.50	+.89
Western red cedar	−.05	±1.0	+.35	±1.0	+.17

AVERAGE DEVIATIONS

Western white pine	±7.4	±11.6	±8.5	±11.1	±8.5
Western larch	±8.4	±15.7	±8.2	±12.2	±8.6
Western hemlock	±8.2	±11.8	±8.6	±10.3	±7.9
Lowland white fir	±8.0	±15.8	±8.2	±13.6	±8.0
Douglas fir	±9.9	±23.3	±9.8	±15.4	±9.7
Western red cedar	±8.0	±15.6	±6.7	±11.9	±8.3

One interesting point brought out in Table 70 is that the average deviations for total-height tables, both Scribner and international, are materially higher than the average deviations for the corresponding merchantable-height tables. This is probably due to inconsistencies introduced by the variability of top length above the merchantable upper diameter limit, a factor present in total-height but eliminated in merchantable-height tables. Other things being equal, merchantable-height volume tables are, therefore, somewhat more accurate than corresponding total-height tables.

Another peculiarity of total-height tables is that they show seemingly ridiculously low values for trees of small dimensions. The explanation is, of course, that these tables are built to show average merchantable contents. The smaller diameter classes often include trees that do not contain a 16-foot log and are unmerchantable by the standards adopted in this study. The tabular value for these smaller classes, therefore, must be proportionately low, since in applying the total-height tables the tabular value will be multiplied by the total number of trees tallied in each diameter class regardless of whether or not all such trees are merchantable.

TABULAR LIMITATIONS AND APPLICABILITY

Some limitations of these tables should be emphasized. (1) They are directly applicable only to trees growing in second-growth western white pine stands. (2) The tables for lowland white fir and western hemlock are rather weak as to tree basis and the basic data are somewhat localized. These tables should be replaced when additional tree measurements drawn from a wider range of localities become available. Within these limitations, however, except for such minor changes as are found necessary in specific cases of local application, these tables are considered applicable regardless of such factors as site and general locality, and stand composition, density, and age. A thorough mathematical study along multiple correlation lines indicates that these factors do influence tree form and hence tree volume to some extent. But this influence is relatively weak, and the studies indicated that a volume table based on diameter and height alone would be sufficiently accurate for all practical purposes.

To check the applicability of the volume tables in any particular locality: (1) Fell and scale a number of trees of various sizes well distributed over representative areas. Twenty-five or thirty trees should be the minimum number measured for each check. (2) Compare the gross scale of each tree measured with the tabular volume for a tree of the same dimensions, and express the difference between these values as a percentage of tabular value. The sum of these percentage deviations (disregarding sign) divided by the total number of trees measured is termed the average deviation. (3) Compare the total scale for trees measured with the total scale for trees of similar sizes as read from the volume tables. The difference between these sums, expressed as a percentage of the total actual scale, is called the aggregate difference. (4) If the average deviation computed is of about the same magnitude as the average deviation shown in the footnotes of the table, and if the aggregate deviation computed does not exceed two and a half times the computed average deviation divided by the square root of the number of trees measured, then the table may be applied without adjustment. If the variation materially exceeds these limits, however, the volume tables must be adjusted for local use. To make this adjustment, average the percentage relationship between check trees and corresponding tabular values for each inch class represented in the check trees, and plot these values over diameter. Draw a smooth balanced curve through these percentages. If the relationships are not uniform for trees of all height classes, group tall, medium, and short trees separately and prepare a curve for each group. These curve readings will indicate how much to raise or lower tabular values to correct for local conditions, and a table so prepared should be accurate for local use.

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AGRICULTURAL CREDIT CORPORATIONS AFFILIATED WITH COTTON COOPERATIVE MARKETING ASSOCIATIONS

BY

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Bureau of Agricultural Economics

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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WASHINGTON, D. C.

AGRICULTURAL CREDIT CORPORATIONS AFFILIATED WITH COTTON COOPERATIVE MARKETING ASSOCIATIONS [1]

By WILLIAM H. ROWE, *Agricultural Economist, Division of Agricultural Finance, Bureau of Agricultural Economics*

CONTENTS

	Page
Introduction	1
Characteristics of organization	5
Capital-stock features	5
The stockholders	6
Control and management	6
Relationship between the corporations and the cotton associations	7
Types of loans	8
Production credit loans	8
Harvest loans	8
Loans to obtain delivery at picking time	9
Supplementary loans on pooled cotton	9
Miscellaneous types of loans	10
Operating practices	11
Procedure in making loans	11
Control and follow-up of use of funds	13
Collection of loans	14
Loan requirements	14
Considerations in passing upon loans	14
Rejections	15
Limits to size of loans	15
Security for loans	16
Term of the loans	18
Loan experience	18
Volume of loans	18
Size of loans	21
Carry-over	23
Losses	25
Rediscount relations with the Federal intermediate credit banks	26
Lines of credit and excess-collateral requirements	26
Volume of rediscounting	28
Rediscount rates and margins allowed	32
The banks' examination of loans	33
Causes of dissatisfaction	33
Costs of loans to the borrower	33
Rate of interest	34
Factors modifying rate of interest in ascertaining cost to borrower	35
Final cost to the borrower	37
Income, costs, and profits	39
Operating statements	39
Operating figures per loan and per dollar of loan	41
Reasons for small profits	42
Comparison with the earnings and expenses of banks	44
Supplementary sources of income	46
Income-tax provisions	46
Dividends, reserves, and surpluses	47
Special problems of credit corporations	47
Ownership of stock by borrowers	47
Local loan groups	50
Extent of affiliation with cooperative marketing association	51
Excessive hazards of the loans	52
An appraisal of the corporations	54
Agricultural credit corporations as a source of credit for farmers	54
State-wide operations	57
Relations with cooperative marketing associations	58
Conclusions	60
Appendix	62
Contract between Growers Agricultural Credit Corporation and members of local groups	62

INTRODUCTION

The precipitous drop in cotton prices from 40 cents a pound in June, 1920, to 11 cents in March, 1921, gave an impetus to the

[1] This study was planned and initiated in cooperation with the Division of Cooperative Marketing, which was later transferred to the Federal Farm Board. Two of the case studies made as part of this general study have been mimeographed as preliminary reports. They are The Texas Cotton Growers Finance Corporation, and An Analysis of The South Carolina Agricultural Loan Association. Acknowledgment of assistance is made to the officers of the corporations who contributed liberally of their time; to numerous persons who read the manuscript critically, and particularly to Fred L. Garlock, who contributed much to the analysis. Credit is due Mrs. Martha Marceron Adams and Mrs. Pauline Luxford for the preparation of the statistical material.

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in some areas of the region is often difficult to obtain, even at high rates. Crop failures and low prices for cotton have cut deeply into the lending resources of banks and merchants. Bank failures since 1920 have been exceedingly numerous, resulting in a loss to many farmers of their only available source of cash credit at the same time that their current working and reserve funds were lost. Hence, the new financing service for members was in many cases a real attraction, particularly since the cost of funds from agricultural credit corporations was often less than the cost from other sources.

TABLE 2.—*Cost on a per annum basis of credit in Southern States*

State	Cash credit			Merchant credit		
	All	Owner	Tenant	All	Owner	Tenant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
North Carolina [1]	7.7	7.7	7.9	25.5	27.7	20.9
South Carolina [1]	9.6	8.8	10.5	31.6	32.6	30.4
Georgia [1]	11.5	8.6	16.0	26.3	27.1	26.0
Arkansas:						
Craighead County [1]	8.7	8.7	8.7	17.7	13.5	18.9
Altheimer district	8.8	7.7	10.0	.....	20.0	41.5
Rison district	10.0	10.0	.....	.....	18.0	20.0
Louisiana	8.1	.....	.....	16.6	.....	.....
Oklahoma [1]	11.4	11.0	11.6	34.8	18.4	38.5
Texas	9.4	.....	.....	27.0	.....	.....

NOTE.—Data are averages obtained from eight separate studies made by the sampling method between 1927 and 1930. Reports of these studies were published by the agricultural experiment stations of the various States, the Bureau of Agricultural Economics cooperating in the preparation of all except those in Louisiana and Texas. North Carolina Bul. No. 270, South Carolina Bul. No. 282, Georgia Bul. No. 153, Arkansas Bul. No. 233, Arkansas Bul. No. 228, Louisiana Bul. No. 208, Oklahoma Bul. No. 198, and Texas Bul. No. 351.

[1] Averages weighted according to the size of the loans.

The cotton cooperative associations were quick to take advantage of the Federal intermediate credit system. By 1924, 4 credit corporations had been formed and were lending money to members of the affiliated associations. In 1925, 4 more were in operation. In 1926 another 4 were added to the list; in 1929, 1; in 1930, 2, and in 1931, 2. Thus a total of 17 credit corporations have been organized although not all have continued operation or maintained their affiliation with the marketing associations. Their location and their significance as represented by the volume of loans made up to and including 1930, are shown in Figure 1.

Agricultural credit corporations affiliated with cotton cooperative marketing associations classified as to first years of operation, 1924–1931, are as follows:

1924

North Carolina Agricultural Credit Corporation, Raleigh, N. C.
Staple Cotton Discount Corporation, Greenwood, Miss.
Agricultural Credit Corporation, Oklahoma City, Okla.
Texas Cotton Growers' Finance Corporation, Dallas, Tex.

1925

Growers' Finance Co., Atlanta, Ga.
Alabama Farm Bureau Credit Corporation, Montgomery, Ala.
South Carolina Agricultural Loan Association, Columbia, S. C.
Cotton Association Credit Corporation, Little Rock, Ark.

1926

Tennessee Agricultural Credit Corporation, Memphis, Tenn.
Louisiana Agricultural Credit Corporation, Shreveport, La.
Mississippi Farm Bureau Agricultural Credit Corporation, Jackson, Miss.
Southwestern Cotton Credit Corporation, Phoenix, Ariz.

1929

California Cotton Growers' Finance Co., Delano, Calif.

1930

Alabama Cotton Credit Co., Montgomery, Ala.
Cotton Credit Corporation, Memphis, Tenn.

1931

Growers Agricultural Credit Corporation, Raleigh, N. C.
Production Credit Corporation, El Paso, Tex.

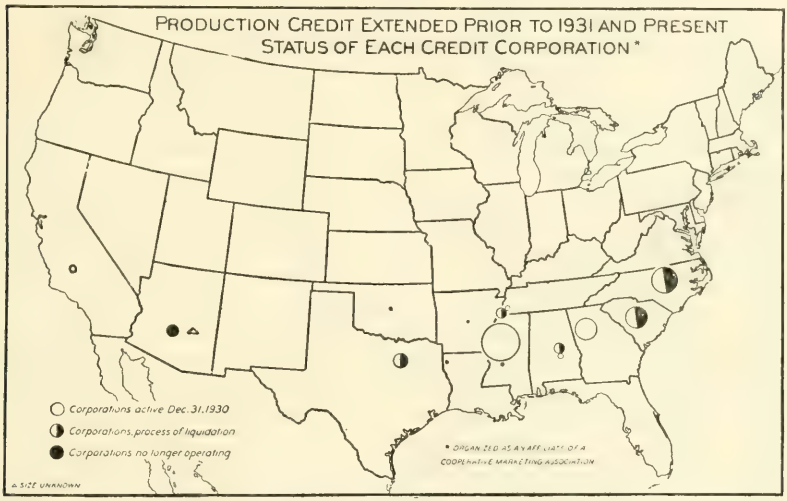
PRODUCTION CREDIT EXTENDED PRIOR TO 1931 AND PRESENT STATUS OF EACH CREDIT CORPORATION *
Corporations active Dec. 31, 1930
Corporations, process of liquidation
Corporations no longer operating
* ORGANIZED AS AN AFFILIATE OF A COOPERATIVE MARKETING ASSOCIATION
A SIZE UNKNOWN

Figure 1.—Agricultural credit corporations organized as affiliates of cotton cooperative marketing associations prior to 1931. The size of the circles indicates relatively the volume of production credit extended by each prior to 1931

CHARACTERISTICS OF ORGANIZATION

The agricultural credit corporations that have been formed by the cotton cooperative marketing associations as a rule have been organized under the general corporation laws of the States in which they operated and have been subject to the regulations that cover ordinary commercial corporations rather than to those covering banking institutions. One of the corporations was organized under the statutes governing cooperative associations in the State.

CAPITAL-STOCK FEATURES

The capital structures have usually been simple, the customary practice being to issue only one type of stock. In two cases, a few shares of special no-par-value stock have been issued in addition to the regular stock. In these cases, the no-par-value stock had the

entire voting power and was held by the directors and the cooperative marketing organizations that promoted the corporation. Prior to 1930, preferred stock had been issued by only one corporation; it was not preferred as to dividend and assets as is customary with preferred stock but was rather a special stock planned for ownership by banks.

The par value of stock issued by these corporations has varied. In several cases it has been $10 per share, and in others it has been $25 and $100. Low par-value figures have generally been used in order to make it possible for individuals to own small amounts of the stock.

THE STOCKHOLDERS

In general, the ownership of stock has not been limited to any particular group. The corporations have been glad to sell their stock to anyone who would buy it, and no need for restrictions has been felt. One exception is that of a corporation which limited the ownership to members of the cooperative marketing association who were actually cotton growers.

Stockholders may be classed in three general groups. First, the cotton associations themselves. In three cases the cooperative association has owned all the stock except a few shares held by the directors of the corporation. In nine cases, the cooperative association has owned only a part of the stock of the corporation, but that part has been either the voting stock or a sufficient amount of the common stock to control the election of directors. Hence, 12 of the corporations have been distinct subsidiaries of the cotton cooperatives. In the case of four others, the cooperative associations have owned no stock whatsoever in the affiliated credit corporations.

The second group has been that of the incorporators, consisting usually of officers and directors of the cotton association and officers and directors of the corporation. The amount of stock held by this group has often been only nominal.

The third and most important group of stockholders has been the borrowers. Most of the corporations have required their borrowers to purchase stock, in an amount usually equal to 10 per cent of the loan. This provision has enabled the corporations to increase their capital as their volume of business grew. In one corporation, the stockholders were all members of the cotton association. They invested no cash, but the cotton association advanced the funds and charged the amount subscribed by each member against his equity in the association's reserves.

CONTROL AND MANAGEMENT

In all corporations except one the privilege of voting has been allotted among the holders of voting stock in proportion to the number of shares held. In the case of the exception each member has had one vote regardless of the number of shares owned. The managements of the cotton associations as a rule have experienced no difficulty in maintaining control as little interest is taken by stockholders in their voting rights. Furthermore, the stock has been

widely scattered in small lots, and the managements have found that by asking for proxies they can readily control the affairs of the corporations.

As a rule, the directors of the finance corporations have consisted of all or a part of the directors of the cotton associations. They have not usually taken an active part but have left most of the decisions to the officials.

Officers of a credit corporation have generally been a president, vice president, secretary, and treasurer, elected by the directors from their own group, and a manager who was appointed. Active affairs of the corporation have usually been handled by the manager under some supervision from the president, who almost invariably has been the president also of the cotton association.

In only one corporation have specific restrictions been placed on loans for farming purposes to directors and officers. In that instance, the directors and officers are permitted to obtain loans only if they pledge marketable securities or other investments in excess of the amount of the loan.

RELATIONSHIP BETWEEN THE CORPORATIONS AND THE COTTON ASSOCIATIONS

The relationship between the cotton associations and the credit corporations, although not always that of parent and subsidiary, has in most cases been very close. The two organizations have usually been under the same management, working toward one goal. They have often been located in the same building and sometimes in the same office. In some instances, the employees of the association have done the work of the corporation also, and in one case the association has paid all the expenses. In all cases loans have been collected through the association out of amounts due the members for their cotton. The two organizations have in some cases loaned money to one another, the association lending to the corporation in the spring when loans are being rapidly advanced and borrowing in the fall the inactive capital funds of the corporation.

Regardless of how close the relationship and regardless of the fact that to outsiders and to members they have appeared as one and the same organization, they have been in the eyes of the law two separate and distinct entities, and neither has been responsible for the debts of the other.

A rather loose relationship existed in the case of the first North Carolina and the South Carolina corporations. The cotton associations owned no stock of the finance corporations, and commercial banks as well as the associations were instrumental in organizing the corporations. The credit corporations served not only members of the State cotton cooperative associations, but also members of the Tri-State Tobacco Association and, in later years, farmers who were members of no association. In both of these cases, the only relationship that existed between the management of the corporation and the cotton association was that some directors of the cotton association were also on the board of directors of the corporation. The two organizations were not located in the same offices, nor was the administrative work done by the same staff. At present both credit corporations are entirely independent of the cotton associations.

TYPES OF LOANS

Most of the agricultural credit corporations that have been mentioned were organized by the cotton cooperative associations primarily for making production loans on cotton. A number of other kinds of loans have been made also, some of them to aid the cotton cooperative associations as such and others chiefly to aid the members of the associations.

PRODUCTION CREDIT LOANS

Advances for production include by far the largest part of the loans made by these corporations and constitute the primary feature with which this study deals.

A crop-production loan is one made to finance the growing of a particular crop, or all of the crops, of a particular farm. It is usually secured by a lien on the crops and often with such additional security as is available. Loans made by these credit corporations have been largely for growing cotton, but some corporations have made loans for the production of tobacco and peanuts, and even for dairy products. Loans, although made on the basis of cash crops, are used for the production of feed and food crops as well. Funds obtained by rediscounting loans with the Federal intermediate credit banks must by law be used only for agricultural purposes. Furthermore, it is the custom to require that the money loaned be put into the production of a crop. Production purposes are generally construed to include purchase of fertilizer, seed, and feed, advances to tenants for living expenses, and a small advance for the necessary living expenses of the borrower. In some cases, borrowers are permitted to use the funds for the purchase of livestock and implements and for drainage work.

The distinction between production loans and other types of loans is not always clear and varies in individual cases. Loans for some of the purposes enumerated above border closely on consumption loans, whereas in other cases they border on loans for capital investment.

Production loans are subject to all the risks of the crop, including those arising from inclement weather, floods, boll-weevil and other insect infestation, and shortage of labor. In addition, they are subject to the risk of a drop in the price of the products grown. There is also the personal risk; the borrower may not know how to manage his farm, he may not be industrious, or worst of all, he may even be dishonest.

HARVEST LOANS

Two of the corporations have been making additional loans to the borrowers at picking time if needed; these are called harvest loans. One of them has made such loans in the form of an additional advance. The other has permitted the borrower to keep a part of the early proceeds from the liquidation of his crop instead of requiring that all such proceeds be applied immediately to the repayment of the production loan. In one case, the corporation at the time of this study was limiting the loans of such character to 15 per cent of the estimated value of the crop. The other corporation customarily allowed $15 a bale on all cotton delivered, although the amounts varied from $5 to $25.

LOANS TO OBTAIN DELIVERY AT PICKING TIME

Several of the corporations have been making loans at picking time to association members who could not deliver their cotton because of objections by creditors holding mortgages on the crop. The Arkansas corporation handled only this type of loan. The corporation paid off the loan and took over the mortgage.

As these loans are of short duration, and as a number of the hazards of the crop have been successfully passed, the risk is not so great as on production loans. Nevertheless, the few weeks or months during which the loan is outstanding cover a critical period. The borrower may sell all or part of the cotton and thus jeopardize the security of the loan; the cotton is open so that wet weather may seriously reduce its quality and value. Then, too, the cost of making these short loans is little if any less than the cost of loans for longer periods, and the small amount of interest collected on the loan during its short term hardly justifies the risk and expense involved. To the cotton association, however, the delivery of a bale of cotton obtained by such a loan is just as satisfactory as the delivery of a bale obtained through a production loan.

SUPPLEMENTARY LOANS ON POOLED COTTON

Loans on delivered cotton, supplementary to the advances made by the associations, have been made by two of the corporations. The advance of 60 to 65 per cent of the value of the cotton when placed in the seasonal pools was as much as the cooperative associations could borrow from the banks by pledging the cotton as collateral. It was felt that if this advance could be increased, membership in the cooperative would become more attractive. As a matter of fact, some members needed an amount larger than 65 per cent of the value of the crop to enable them to pay off the loan on the crop and to obtain a release of the mortgages in order that the cotton could be delivered to the association.

Officers of these associations felt that a larger advance could be made safely; they used the affiliated credit corporations for this purpose. These supplementary loans were secured by assignments against the proceeds from the equities of borrowers in cotton that had been delivered to the association.

The amount of the loans was determined by various factors. Needs of the borrower, his character, and his reputation, were considered. Although the element of character might be largely disregarded in the association's advance of 65 per cent of the value of the cotton, that element could not well be disregarded when increasing the advance to perhaps 80 per cent through a supplementary loan.

Other factors determining the size of the loans were the quality of the applicant's cotton, and the price of cotton. The association's original advance was made uniformly on all cotton but before the supplementary loans were made, the cotton was classed as to grade and staple. If the grade and staple of the applicant's cotton were above the average, the excess value of such cotton was reflected in the size of the supplementary loan granted. If there had been a marked change in the price of cotton between the time of the

original advance and the time of application for a supplemental loan, that fact would affect the size of the loan.

The experience with loans of this type was not so bad as might be expected. Falling prices during the marketing seasons for 1926 and 1928 cotton made it necessary in many cases to call for payment of the note or pledging of additional collateral. Losses, however, were small, and in the case of one of the corporations they were taken over by the cooperative marketing association.

Loans of this type, like those made to obtain delivery at picking time, have not been rediscountable with the Federal intermediate credit banks. Usually they were made out of the capital funds of the corporation or out of funds obtained by loans from the cotton associations or other sources. The granting of supplementary loans on pooled cotton to the cooperatives by the Federal Farm Board during 1929 and 1930 have made such loans by the affiliated credit corporations unnecessary.

MISCELLANEOUS TYPES OF LOANS

Two of the credit corporations have made some loans on dairy cattle. The usual amount of the loans has been 50 per cent of the value of the stock. Loans have been made only if there has been a satisfactory market for the products. These loans have been repaid in monthly installments and hence have involved more work, particularly if the borrower has been lax about making payments promptly each month. Although the margin of interest that the corporation has earned on such loans has been one-half of 1 per cent larger than on crop loans, the business has not been profitable because of the heavy expense. At the time these data were being gathered it did not appear likely that the practice of making dairy-cattle loans would be greatly extended as the credit corporations were operated by the cotton-marketing associations and had little interest in dairying. Extremely low prices for cotton since that time, however, have led to a strong movement for reduction in cotton acreage, and the cotton associations may possibly approve or even encourage loans for the production of commodities other than cotton.

A few miscellaneous loans have been made by the various corporations, such as loans on eggs in storage, loans to fertilizer companies as advances for delivery of fertilizer, and loans to other credit corporations. Even farmers' notes for purchase of windmills have been rediscounted. Most of these miscellaneous loans have been made at the instigation of the parent association. In these cases the association has used the finance corporation as a convenient lending medium and would have made good any losses.

Loans have been made by a few corporations to employees and officers of the corporation and the cotton associations. Such loans are not generally looked upon with favor unless they represent advances for traveling expenses or other business purposes.

In several corporations, surplus funds have been loaned during the fall and winter to the cotton association. It has been the usual practice to charge interest at the rate which the association was paying elsewhere. Some corporations have made the loan on open ac-

count; others have taken warehouse receipts from the association on the same basis as a bank would lend it money.

OPERATING PRACTICES

The first credit corporations that were formed had little precedent or experience to follow in determining their practices and policies. The Federal intermediate credit banks also were new organizations without experience. As a result of years of experience, however, a fairly satisfactory set of practices is now established. Considerable uniformity is to be found among the corporations, owing partly to the influence of the Federal intermediate credit banks, and partly to conferences between the officers of the credit corporations in various States.

PROCEDURE IN MAKING LOANS

The first step in the procedure of making a loan is to have the farmer make application in writing. The application gives information relative to the financial condition, farming ability, and probable income of the applicant. A form used by one of the corporations for this purpose is shown in Figure 2. The borrower is required also to present a financial statement showing his assets, liabilities, and net worth. He must show both actual and contingent liabilities. Some corporations require a list of tenants and the basis on which they are employed; some require a list of livestock, with a description of each animal; others require a list of all the chattels.

As they operate usually over a whole State it is necessary for the corporations to have some way of making local contacts. The association field men are used by some corporations, whereas others employ field men of their own. These field men accept applications, and often examine the farms of the applicants and the security for the loans. Some corporations have appointed persons in various cities and county seats to take applications for loans. They do not as a rule examine the farms and property of the applicants, but they are often familiar with the applicant's credit standing.

One organization, the Texas Cotton Growers Finance Corporation, has found it desirable in some counties to use local loan committees, often composed of the county agent, one or two farmers of good standing who are members of the cotton association, and other persons of good repute. These committees accept applications, pass upon loans, and recommend or refuse them. They are advisory only and assume no financial responsibility. They work for practically no compensation except the satisfaction of rendering a semipublic service. To be successful a committee of this sort must be made up of individuals of a very high type.

When the application is finally received at the corporation's office, it is examined and passed upon by the manager. (In some organizations, the manager's work is simplified by first having a clerk examine the papers as to completeness and accuracy, and in some instances there is a loan committee to which the manager presents his findings and which ultimately approves or disapproves the loan.) Almost invariably, if the loan is approved by the corporation, it must be approved by the Federal intermediate credit bank for rediscount before it can be granted, for the corporations have little money

APPLICATION FOR LOAN

(IN DUPLICATE)

TO..... ....
(Name of bank) (Address) (Date)

1. Application is hereby made for a loan for $....., the proceeds of which are to be used for making my crop.
2. I own the following amount of stock in the Staple Cotton Discount Corporation, $.....
3. Yields of Cotton for last five years on land in cultivation this year are as follows.

	Crops for Last 5 Years	Acres in Cotton	Number Bales Ginned	Value of Cotton
4.	19..... CROP	A.	B/C.	$
5.	19..... CROP	A.	B/C.	$
6.	19..... CROP	A.	B/C.	$
7.	19..... CROP	A.	B/C.	$
8.	19..... CROP	A.	B/C.	$
9.	TOTAL			$ .....

10. Average value per acre $.....
11. 50 per cent of average for the 5 years. (Divide total by 10) $.....
12. 75 per cent of smallest crop $.....
13. Do you own all lands in cultivation this year: .....
14. If not, amount of rent to be waived: .....
15. Acres in Cultivation this year:.....Acres in cotton: .....Acres in feedstuffs: .....
16. Number families Last Year.....This Year:.....Average work hands to family: .....
17. Labor employed as follows: No. Cash renters.....No. cotton renters:.....No. Sharehands: .....
18. Number white tenants:.....How many families do you supply:.....
19. Will you control the sale of all cotton covered by this application: .....
20. How many head of work stock:.....Mules: ..... Horses: .....
21. Where did you obtain funds last season for making crop:.....
22. How much balance, if any, do you owe $.....
23. I hereby agree, in the event the notes securing this loan are discounted by the Staple Cotton Discount Corporation, that:
    (a) Said corporation shall deduct one (1) per cent of the total loan and said amount shall be placed in the Reserve for Losses account of the said corporation.
    (b) All cotton produced on the property covered by this application will be promptly ginned and delivered to Staple Cotton Cooperative Association.
    (c) Reports with reference to the condition of the crop and the harvesting thereof will be furnished said corporation when requested.

(Signed) .....

(Address) .....

I, an officer of this bank, do hereby certify that I am familiar with the affairs of the farmer or other individual whose name appears on this application for a loan and that, to the best of my knowledge, the above is a true statement; and that I have authority by order of the Board of Directors to discount the paper covering the above application.

(Bank) .....

(Officer) .....

FIGURE 2.—Sample form of application used by one of the corporations included in this study

of their own to lend. Hence, the papers are next sent to the Federal intermediate credit bank.

If the loan is approved by the bank the following forms are prepared in the office of the corporation: A note; a mortgage, lien, or bill of sale on the crop, livestock, and implements; an assignment in favor of the corporation of cotton to be delivered to the association; and papers for any other security required. These papers are sent to the applicant for signature and for recording of the liens. The applicant is also required to obtain, from some county officer or an attorney, a statement showing that no prior liens are recorded against the crop or chattels. Upon return of these papers to the corporation office, they are examined carefully; if correct, they are sent to the Federal intermediate credit bank. In most cases, the corporations find it necessary to await the remittance from that bank before advancing the funds to the borrower.

This long and detailed procedure, involving the approval of the loan by a local representative or loan committee, then by the manager of the corporation, then by the executive committee, and finally by the Federal intermediate credit bank, requires much time. The papers usually must be sent through the mails to the corporation's office, from there to the Federal intermediate credit bank, back to the corporation, then to the borrower for signature and recording, then back again to the corporation, which forwards them to the bank. The remittance is then sent from the bank to the corporation, and the corporation sends it to the farmer. Thus, eight trips through the mail are required before the farmer gets his money.

A week is about the shortest period possible for these operations under the most favorable circumstances; from two to three weeks is customary. It is little wonder that one of the chief complaints against the system is the time and delay involved. In fact, the length of time required to get loans from the agricultural credit corporations, together with the uncertainty of the farmer during that period as to his source of funds for the year, is one of the reasons why more farmers have not borrowed from the corporations.

The Federal Intermediate Credit Bank of Columbia attempts to meet this difficulty by requiring that applications sent to the bank include all papers completed and ready for rediscount with the mortgages or liens recorded. To require the applicant to record a mortgage some weeks before he knows whether he will be able to get the loan may be a strict requirement, but the practice helps him to get his money sooner than would otherwise be possible, and if the loan is refused the mortgage is released.

CONTROL AND FOLLOW-UP OF USE OF FUNDS

To be assured that the funds loaned will be put into the crop, most corporations advance some of their loans in installments. One organization uses the monthly installment method almost exclusively. This practice prevents the borrower from spending all or an undue proportion of the money in the early part of the season. Such indiscretion is likely to necessitate the granting of a supplementary loan to save the crop, with the result that the total of the loans on the crop is larger than was originally considered justifiable. Another advantage of advancing the funds in installments rather

than in a lump sum is that the money is not withdrawn in advance from the Federal intermediate credit bank, or it is kept in a large city bank where there is little danger of bank failure. Loss of funds by the borrower through failure of a local bank often means a carry-over or a loss for the corporation because the borrower has to have another loan if he is to make his crop.

Credit corporations find it necessary to watch closely the growth of the borrower's crop, because that crop frequently is the most important part of the security. As many as two or three visits during the summer are sometimes made to observe the progress of the growing crop, the character of the cultivation, and the danger from boll-weevil damage. If the crop is in danger of being lost, it is often necessary to grant an additional loan so that the farmer can hire extra labor or perhaps put more money into control of the weevil by poisoning. Sometimes if part of the crop is lost, the subsequent monthly advances are reduced. Some associations operating over wide territories have found it impossible to visit isolated farms frequently and have resorted to sending interim letters to the isolated borrowers asking about the climatic conditions, the condition of the crop, and the prospects for yield.

COLLECTION OF LOANS

Loans are not customarily collected in cash, but are retired by having the borrower deliver his cotton to the marketing association. The original advance and the following distributions on that cotton are then paid by the association to the finance corporation instead of to the farmer until the loan is completely paid off. Consequently, it is very important that the field staff be active during the picking season, and in some cases extra field men are added. Field men visit the borrower at this time, estimate the size of the crop, and make the borrower understand that he is expected to deliver all of the crop in payment for the loan. If the field man estimates the approximate yield, any unreliable borrower is more hesitant to sell a part of his crop for fear he will be found out. The very fact that the corporation field men are actively watching the crop at harvest time results in a much better collection of the loans.

LOAN REQUIREMENTS

In order to make safe loans it is necessary that certain requirements and standards be set. It is also necessary that those standards be rigorously adhered to. The stated requirements for loans by these various corporations have often been similar, but the extent to which they have been followed out in practice has differed. The results of differing practices are, to some extent, reflected in the present financial standing of these companies.

CONSIDERATIONS IN PASSING UPON LOANS

The first consideration in passing upon a loan is the character of the applicant. If an individual takes advantage of every opportunity to avoid paying a debt, it is considered best to refuse his application without further consideration. Even though the loan be well secured and the papers carefully drawn, a loan to such an

individual is a source of trouble and expense. A problem just as difficult is to exclude those applicants who, although they will not absolutely attempt to avoid payment, will not consider the debt a binding personal obligation and will let the corporation shift for itself if the security becomes impaired or exhausted. Other personal characteristics such as industry, resourcefulness, and general capability are also considered.

Since the loan is for the purpose of making a crop, the probable yield and value of that crop limit its size. The applicant's knowledge of farming and his ability to produce a crop must be weighed along with the probable prices of the products, so as to determine the probable income. To eliminate the uncertainty of the income for the year, some corporations almost invariably recommend diversification of crops, and all corporations require the production of feed crops. They are more inclined to look with more favor on the applications of those farmers who have sufficient feed of their own to take care of the livestock through the growing season. Of course safe margins must be demanded between the probable income from the crop and the amount of the loan.

The borrower's equity in his farm and his net worth are important considerations. For instance, an applicant showing substantial net worth would be granted a larger loan on a given expected income than would an applicant with less wealth. Of late years, owing to the depressed condition of cotton prices and of agriculture in general, there has been a tendency to limit the loans to amounts that could be paid by liquidating the assets of the borrower. Some believe that this practice is the only safe basis on which to lend.

Most of the corporations make loans to tenants who own the livestock and equipment on the farm they rent. Some corporations make such loans only if the landlord endorses the paper. In other cases the landlord is expected to sign a waiver of the rent; in one State he signs a waiver of all other debts and advances except rent. None of the corporations make loans to share croppers.

REJECTIONS

No information is available for the group as a whole as to the number and amount of rejections. Many loans are rejected by field men and other representatives before a written application is ever prepared. Statements by representatives of one corporation indicate that as many as 9 out of 10 persons who asked for loans were refused in 1930. This is probably much higher than a normal ratio of rejections to applications and greatly exceeds the ratio after formal written application is made. Rejections of formal applications by the Texas Cotton Growers Finance Corporation averaged 40 per cent of the number received over a period of four years.[3]

LIMITS TO SIZE OF LOANS

Various limits and standards have been set by the corporations as to the size of loans they will grant. Fifteen dollars an acre on cotton has been a common figure, but with low prices for cotton the

[3] See the following report: ROWE, W. H. THE TEXAS COTTON GROWERS FINANCE CORPORATION. A PRELIMINARY REPORT. U. S. Dept. Agr., Bur. Agr. Econ. [Rpt.] 38 p. 1931. [Mimeographed.]

basis was lower in 1931. The following standards have been used at various times by some of the corporations:

Customary amounts (to be modified if conditions warrant): (1) $15 per acre on cotton; (2) $150 per plow [4] on cotton; and (3) $40 per acre on tobacco.

Maximum limits: (1) 50 per cent of average income for the last five years or 75 per cent of smallest income for any one year, whichever is the smaller. This basis is adjusted for changes in acreage and is reduced in years when prospects of cotton prices are poor. (2) On land yielding one bale per acre, $25 per acre. (3) On land yielding one-fourth bale per acre, $5 per acre. (4) An amount not to exceed a conservative estimate of the value of livestock and chattels. (5) Twenty per cent of the unimpaired capital and surplus of the corporation.

SECURITY FOR LOANS

Whenever a loan is made, a first mortgage, deed of trust, or bill of sale is taken on all the crops. This gives the corporation first claim on the income produced by the funds loaned although it is customary to permit the borrower to sell the cottonseed to meet the extra expenses of the picking season. In the case of carry-over loans, if the corporation does not finance the new crop, it does not as a rule get the mortgage, for the new mortgage is given to the party who finances the new crop.

A first lien is also required on the livestock and implements of the borrower. In some sections where the livestock and implements owned by the borrower often consist of little more than a mule, a plow, and a cultivator per tenant, the actual value of this security is not high. In the fall the mule may sell for $25 or $30, while the implements will probably sell for very little. If the loan per plow has been $150, a foreclosure of this mortgage will not usually bring enough to complete the payment of the loan. Moreover, foreclosure of the mortgage would put the farmer out of business and in most cases destroy all chances of collecting the unpaid balance. It is the view of the officers of one of the Federal intermediate credit banks that the mortgage on livestock and equipment has a value quite aside from its foreclosure value. The existence of this mortgage prevents the borrower who deserts his crop from selling or taking the livestock and equipment with him. Thus the corporation, which stands to benefit by every cent salvaged out of the crop, can employ labor to carry the crop to completion, for the work stock and tools are still at hand.

In other sections the livestock and implements represent a larger part of the wealth of the borrowers and are more important as security. One of the corporations, for instance, has limited its loans to a conservative estimate of the value of livestock and implements. Sample data of borrowers, picked from the records of five corporations, indicate average ratios between the size of loans and the value of the livestock and implements as follows: 1.92, 0.38, 1.14, 1.20, and 1.34. Strange as it may seem, the corporations with the highest and

[4] A man, his family, and a mule.

lowest ratios had had the best collection records at the time the data for this study were obtained, although both have suffered from the effects of low cotton prices and drought since that time.

Mortgages or deeds of trust are often taken on the land, but these are most often second or third liens. If a borrower is heavily involved, the corporation usually considers it desirable to fortify its position by a land mortgage as well as a mortgage on crop and chattels; this prevents other creditors from getting in ahead. If a borrower fails to pay his loan in any year, it is a common practice to require that he give a mortgage on the land if he has any equity in it. Samples taken for two of the corporations over various periods indicate that 40 and 60 per cent, respectively, of the current loans were secured by land mortgages. With the lower prices of cotton during recent years the practice of demanding mortgages on the land is more prevalent.

Most of the corporations require the borrower to pledge the stock of the corporation, which he is obliged to purchase, as security for the loan. From the point of view of the Federal intermediate credit bank, the practice is unnecessary for, since the corporation indorses the borrower's note, the bank has recourse to it and should the corporation fail so that it could not pay the debt itself, its stock would be worthless as security. Pledging the stock with the corporation, however, has distinct advantages to both the corporation and its stockholders. Borrowers who would not otherwise pay their loans in full, will sometimes do so if their stock is pledged so that they may have the stock free to sell or redeem.

A serious injustice might be done if the stock were not pledged. Borrowers who do not pay their loans and who by such actions might cause the failure of a corporation would be entitled to share in the liquidation of the remaining assets on the same basis as other stockholders. Hence it seems very desirable from the standpoint of the corporation and its stockholders to require a pledge of the capital stock owned by the borrower, even though the Federal intermediate credit bank does not insist upon it. Some agricultural credit corporations not included in this study have a provision recited on the stock certificate that the stock will be considered security for any debt of the stockholder to the corporation.

Other security is taken if the borrower has it to offer. Sometimes bonds, stocks, or other investments may be pledged; sometimes mortgages on town or city property are given. Often the borrower is required to assign life-insurance policies. The reserves of an insurance policy represented by its cash-in value make excellent security, and the policy is particularly valuable as security if there is more than the average probability that the borrower will not live throughout the season.

The borrower is expected to assign to the corporation his equity in all cotton he may deliver to the association out of the crop to be financed. This assignment gives the cooperative marketing association the authority to pay to the finance corporation the original advance on the cotton and any subsequent distributions until the loan is satisfied. If in the spring, when the farmer applies for a loan, he has any equity in cotton held by the association from the preceding

season, he may be required to make an assignment of that to the finance corporation also.

TERM OF THE LOANS

The terms of the loans vary. Until an amendment was made to the agricultural credits act in 1930, loans could not be rediscounted for periods shorter than six months. Some corporations make most of their loans for a definite term such as nine months. Others fix a customary date for maturity of notes, such as December 31. A common practice is to have the note mature at picking time. Thus the note matures and payment is demanded when the borrower has cotton or funds to pay the note. Furthermore, in case the cotton is sold rather than shipped to the association, the legal action for nonpayment of the note is easier to substantiate than is action for disposal of the security.

Although the term of the loan may be from 6 months to a year the usual period during which the loans, other than carry-over, are outstanding is seldom more than 6 to 8 months. An average taken of the length of all loans made in a season by one of the corporations indicated that it was 6½ months from date of first advance in the spring to date of final payment in the fall. The average annual earning period for the loans of four corporations has been 7 months or less. (See tabulation on p. 42.)

LOAN EXPERIENCE

Experiences of these corporations in their lending activities have varied widely. Some of these corporations have been large organizations playing an important part in the financing of the cotton crop; others have been mere experiments. Some have dealt in large loans; others in small ones. Some have collected practically all loans each season, thus making each year's operations a separate enterprise; others since the first year have been burdened with uncollectible loans. Some have been operating continuously since they were organized; others have operated for a year or two and then passed out of existence.

VOLUME OF LOANS

The volume of business done by these agricultural credit corporations is important, for in a sense it measures the amount of service rendered. Table 3 shows the maximum amount of loans outstanding each year for 11 corporations. This list includes all corporations organized prior to 1931 by cotton cooperative associations, except one which operated in Arizona, a small one which operated for two years in Oklahoma, and one in Arkansas which did not make production loans.

TABLE 3.—*Total production loans (new and carried over) for 11 corporations, 1924–1930*

Corporation	1924	1925	1926	1927	1928	1929	1930	Total
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A [1]		99, 703	1, 539, 301	636, 669	760, 836	1, 089, 348	992, 880	5, 118, 737
B	512, 927	616, 926	1, 593, 475	1, 338, 354	2, 140, 544	3, 060, 811	5, 520, 490	14, 783, 527
C			194, 231	495, 444	523, 691	734, 429	668, 372	2, 616, 167
D		37, 978	132, 083	204, 704	275, 005	395, 364	[1] 471, 000	1, 516, 134
E		1, 380, 000	2, 160, 000	1, 421, 000	1, 110, 000	620, 000	350, 000	7, 041, 000
F [1]	1, 130, 000	2, 100, 000	2, 600, 000	965, 000	695, 000	500, 000	425, 000	8, 415, 000
G			27, 000	76, 678	350, 873	840, 830	[2]	1, 295, 381
H [1]				35, 875	50, 000	75, 000	[2]	160, 875
I						10, 580	55, 385	65, 965
J			48, 000	75, 000	[2]	[2]	[2]	123, 000
K							270, 000	270, 000
Total	1, 642, 927	4, 234, 607	8, 294, 090	5, 248, 724	5, 905, 949	7, 326, 362	8, 753, 127	41, 405, 786

[1] Estimated. [2] Either liquidated or not operating.

The volume of business varied greatly among the corporations, the smallest yearly volume for any one being about $10,000 and the largest being about $5,500,000. Loans reached a peak of $8,000,000 in 1926 and then declined. Of late years the volume of loans has increased again, reaching about $8,700,000 in 1930, but $5,500,000 of this was loaned by one organization. In the seven years since the first two corporations were organized in 1924, these corporations have loaned about $41,000,000.

Whereas Table 3 shows total loans, carry-over loans included, Table 4 shows only the amount of new loans made each year. In one or two cases the carry-over loans of a corporation represented more than half of all loans for the year. Furthermore, in 1927 the new loans for all corporations were only 72 per cent of the total loans. This was the result of a rapid expansion of activities in 1926, followed by lower prices for cotton and inability to liquidate the loans. The relationship between the new loans and total loans for all corporations is shown also in Figure 3.

TABLE 4.—*New production loans made by 11 corporations, 1924–1930*

Corporation	1924	1925	1926	1927	1928	1929	1930	Total
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A		99, 703	1, 539, 301	586, 621	670, 472	813, 736	[1] 820, 238	4, 530, 071
B	512, 927	606, 677	1, 591, 604	1, 183, 262	2, 062, 412	3, 027, 260	5, 498, 664	14, 482, 806
C			194, 231	461, 866	495, 997	691, 505	299, 417	2, 143, 016
D		37, 978	128, 382	218, 092	316, 212	367, 775	288, 020	1, 356, 459
E [2]		1, 380, 000	1, 877, 000	468, 000	738, 000	129, 000	0	4, 592, 000
F [2]	1, 130, 000	1, 650, 000	2, 400, 000	700, 000	400, 000	400, 000	[3]	6, 680, 000
G			27, 000	68, 985	344, 940	731, 735	[4]	1, 172, 660
H [2]				35, 875	42, 000	72, 500	[4]	150, 375
I						10, 580	55, 385	65, 965
J [2]			48, 000	75, 000				123, 000
K [2]							270, 000	270, 000
Total	1, 642, 927	3, 774, 358	7, 805, 518	3, 797, 701	5, 070, 033	6, 244, 091	7, 231, 724	35, 566, 352
Percentage of total loans	*Per cent* 100. 0	*Per cent* 89. 1	*Per cent* 94. 1	*Per cent* 72. 4	*Per cent* 85. 8	*Per cent* 85. 2	*Per cent* [5] 86. 8	*Per cent* 85. 9

[1] To Apr. 25.
[2] Estimated.
[3] Unknown.
[4] Not operating.
[5] Corporation F not used in calculation.

Services rendered by these corporations should be measured in terms of the number of loans made as well as the amount loaned. Data are available only for five corporations and only for the new loans of those. Table 5 shows the number of new loans made, by years, for the first five corporations listed in Table 4. One of the most significant features in the table is the progressive growth of number of loans by three of the corporations, whereas the other two

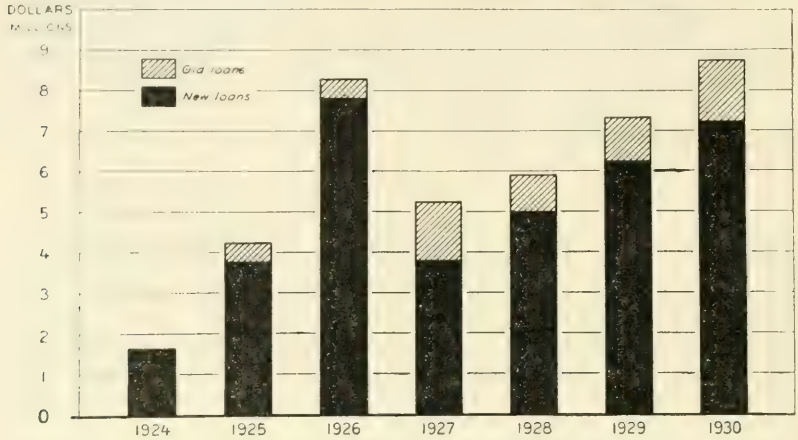

FIGURE 3.—TOTAL AND NEW PRODUCTION LOANS OF AGRICULTURAL CREDIT CORPORATIONS ORGANIZED BY COTTON COOPERATIVE MARKETING ASSOCIATIONS

Total loans rose rapidly within three years to more than $8,000,000 in 1926, but declined sharply the following year. Since 1927 there has been a gradual increase until loans exceeded $8,000,000 again in 1930. Since 1926 the proportion of the loans which are new has been smaller.

made a large number of loans in 1926 but had to retrench thereafter. In 1926 over 4,000 persons were provided loans by these five corporations.

TABLE 5.—*Number of new production loans made by five corporations, 1924–1929*

Corporation	1924	1925	1926	1927	1928	1929	Total
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
A		(1)	1,898	570	571	619	3,658
B	56	55	109	112	152	180	664
C			183	335	360	372	1,250
D		28	80	116	144	168	536
E		1,383	2,109	688	904	302	5,386
Total	56	1,466	4,379	1,821	2,131	1,641	11,494

[1] Data not available.

Two of the corporations have made supplementary loans on pooled cotton to members of the affiliated cotton cooperative marketing associations. To make this type of loan was the purpose for which the Texas Cotton Growers Finance Corporation was organized in 1924; such loans constituted its only lending activity until 1926. At present, this business is of secondary importance, having been replaced by the production credit business. Table 6 gives the loans of this type for two corporations. The year 1925 witnessed

the largest volume of such loans, the total that year being about $700,000.

TABLE 6.—*Supplementary loans on pooled cotton, made by two agricultural credit corporations, 1924–1929*

Year	Corporation A	Corporation C	Total	Year	Corporation A	Corporation C	Total
	Dollars	*Dollars*	*Dollars*		*Dollars*	*Dollars*	*Dollars*
1924	----------	606, 223	606, 223	1927	48, 300	478, 099	526, 399
1925	153, 500	548, 014	701, 514	1928	123, 000	125, 940	248, 940
1926	37, 500	60, 954	98, 454	1929	47, 500	16, 915	64, 415

Loans of other types have been made by several of the corporations, but the amounts have been neither large nor particularly significant.

SIZE OF LOANS

The size of the loans made by an organization is significant. It is indicative of the type of business that the corporation handles and of the general character of the borrowers whom the corporation serves. It is important also from the standpoint of profitable operation, for the interest earned on loans is directly proportional to the size, yet the cost of making and servicing loans bears little relation to the size and is usually about the same for small loans as large ones. It is not known on which class, if any, there is the greater chance of loss, but it is obvious that failure to collect a large loan would be more likely to weaken or wreck a corporation than would the failure to collect a small loan.

In describing the size of loans made by these agricultural credit corporations, two measures have been used, the average and the median. As the average fails to represent the usual size of loans because it is unduly affected by a few large ones, the median is used here also. The median loan is that one with regard to which half of the loans are larger and half are smaller. Table 7 shows the average and median size of loans for five corporations. Since the size of loans of one of the corporations is far in excess of any of the others, it is segregated from the rest.

TABLE 7.—*Average and median size of loans for five corporations, 1924–1930*

Corporation	1924		1925		1926		1927	
	Average	Median	Average	Median	Average	Median	Average	Median
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A	----------	----------	----------	----------	811	400	1, 029	400
C	----------	----------	----------	----------	1, 061	500	1, 379	465
D	----------	----------	1, 356	800	1, 605	700	1, 880	971
E	----------	----------	828	500	890	500	680	379
Average	----------	----------	839	----------	876	----------	870	----------
B	9, 106	5, 800	10, 949	7, 400	14, 679	10, 000	11, 144	6, 000
Average	----------	----------	1, 218	----------	1, 213	----------	1, 226	----------

TABLE 7.—*Average and median size of loans for five corporations, 1924–1930*—Continued

Corporation	1928		1929		1930		Total	
	Average	Median	Average	Median	Average	Median	Average	Median
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A	1,174	500	1,315	643	1,250	650	1,027	
C	1,378	500	1,859	650			1,475	
D	2,196	1,000	2,189	1,040	1,880	700	1,986	
E	816	434	605	330			776	
Average	1,095		1,127				965	[1] 494
B	13,176	8,000	16,515	8,750			13,457	
Average	1,887		2,270				1,531	[1] 533

[1] Approximate.

The median size of loans is much smaller than the average. This is due to the effect on the average of a relatively few very large loans. Median figures for loans are not readily available for all corporations by years or for all years by corporations. The median sizes of the loans made during all years for the groups of five corporations are estimated from frequency distributions shown in Table 8. The calculated medians are much smaller than the final averages.

TABLE 8.—*Size of production loans made by five agricultural credit corporations* [1]

Size group	Number of loans			Amount loaned		
	Number	Per cent of total	Cumulative percentage	Amount	Per cent of total	Cumulative percentage
		Per cent	*Per cent*	*Dollars*	*Per cent*	*Per cent*
Under $100	73	0.5	0.5	4,371		
$100–$249	2,983	20.4	20.9	463,023	2.1	2.1
$250–$499	4,041	27.6	48.5	1,355,443	6.0	8.1
$500–$999	3,492	23.8	72.3	2,253,905	10.1	18.2
$1,000–$1,999	1,987	13.5	85.8	2,521,812	11.2	29.4
$2,000–$4,999	1,200	8.2	94.0	3,449,599	15.4	44.8
$5,000–$9,999	464	3.2	97.2	2,983,229	13.3	58.1
$10,000–$19,999	252	1.7	98.9	3,270,237	14.6	72.7
$20,000 and over	163	1.1	100.0	6,122,908	27.3	100.0
Total	14,655	100.0		[2]22,443,237	100.0	

[1] Data cover the whole period from the date of organization of each to time each study was made.
[2] This total includes $18,710 not classified because a page was missing from the records.

To facilitate the study of size, the loans are grouped into frequency distributions. A distribution of the loans for five corporations covering the whole period of their operation is found in both Figure 4 and Table 8. The size group with the largest number of loans is that from $250 to $499, whereas the group with the largest amount loaned is that of $20,000 and over. The large amount loaned in the last group is attributable mainly to one corporation which makes loans of much larger size than the others. If data of this corporation were excluded from the analysis the largest group according to the amount loaned would be the one from $2,000 to $4,999.

An analysis of loans of $20,000 and over made by the five corporations grouped together is shown in Table 9.

TABLE 9.—*Distribution by size groups of the loans of $20,000 and over made by five corporations* [1]

Size group	Number	Amount	Size group	Number	Amount
		Dollars			*Dollars*
$20,000–$29,999	67	1, 573, 502	$80,000–$89,999		
$30,000–$39,999	43	1, 427, 633	$90,000–$99,999	1	90, 000
$40,000–$49,999	19	803, 700	$100,000–$149,999	5	566, 000
$50,000–$59,999	19	994, 631	$150,000–$199,999	1	154, 000
$60,000–$69,999	6	368, 442			
$70,000–$79,999	2	145, 000	Total	163	6, 122, 908

[1] Data cover the whole period from the date of organization of each to the time each study was made.

The wide divergence in size of loans immediately attracts attention. Whereas the great majority of the loans cluster around the $500 mark, a number of them are more than 200 times that size. The question arises to what extent are the corporations dependent

FIGURE 4.—SIZE OF PRODUCTION LOANS MADE BY FIVE AGRICULTURAL CREDIT CORPORATIONS

The largest number of loans is to be found in the group from $250 to $499; the largest volume of loans is in the group of $20,000 and over. Although very few loans in excess of $20,000 were made, the volume of business provided by such loans represented a substantial part of the total. (Data cover the whole period from the organization of each corporation to the date when each study was made.)

on the income from the large loans to support their main program of making smaller loans? It also raises the question how far is the corporation endangered by making loans of such size?

CARRY-OVER

It is virtually impossible to collect all loans each year. Disaster resulting from flood, hail, drought, excessive rain, or boll-weevil infestation almost invariably claim part or all of the crop of some borrowers. Unfortunately, a few borrowers will usually sell some of their cotton and deliver an insufficient amount for payment on

their debt. Even though all cotton is delivered, low prices in some years will mean that at least a few loans will remain partly unpaid.

The extent to which a corporation can collect its loans each year depends upon certain factors within the control of the management and certain factors not within its control. Those within its control consist of the selection of credit risks, the relative size of the loans, the supervision of the growing of the crops, the activities of the field force of both the corporation and the association in getting the cotton delivered, and the success of the management of the cooperative association in selling at good prices. Factors not within their control consist of the general condition of the crop, which is very largely a result of weather conditions, and the general level of cotton prices. Wide variations in the experience of the different corporations have been due to factors both within and outside the control of the management.

The term "carry-over," frequently is used loosely. It may be interpreted to mean the amount of a season's loans unpaid when lending activities for the next season are begun or it may mean the amount of a season's loans that must be paid out of income from the crops of some subsequent season. For most farmers there is but little difference, but for the farmer who is a member of a cotton cooperative there is considerable difference. Until the Federal Farm Board made provision for supplementary loans, association members ordinarily received only about two-thirds of the value of their cotton at the time of delivery. Some cooperative associations were able to pay additional amounts throughout the marketing season and to make a final settlement the following summer. Other associations were unable to make final settlements at the end of each marketing year. Many borrowers, although not able to pay their debt out of the original advance of two-thirds of the value of their product were able partly or entirely to liquidate the balance out of their equity in cotton held by the cooperative association. Thus the amount of loans outstanding when lending operations were renewed each spring would be inflated because the equities of borrowers in pooled cotton had not been liquidated.

Data relative to the carry-over by the five corporations studied are not uniform and satisfactory, principally because of lack of classification of loan accounts. Records of some corporations contain one account only for all loans and discounts; loans of all types including production credit, supplementary advances on pooled cotton, harvest loans, and other loans for current and all past years are combined in one account. Furthermore, few of the corporations segregate their production loans into separate accounts for each season's business. If an account had been kept for each type of loan for each lending season the carry-over at any date from each year's loans would be readily available.

The best figures available with a uniform date for the five corporations are the loan-account balances outstanding at the close of each calendar year. These are shown in the top half of Table 10 and are subject to the following modifications if interpreted as carry-over: (1) Figures for corporation A include many supplementary loans on pooled cotton made in the fall of the year and thus are much in excess of the carry-over of production loans; in fact in some

years they are in excess of the total production loans. (2) Collections between the end of the calendar year and the beginning of the new lending season are often very large. (3) Little except the initial advance on the borrower's cotton has been used to reduce the loans by December 31, the remaining equity in the borrower's cotton being available for further reduction of the loans only at a later date.

TABLE 10.—*Carry-over of production loans of five agricultural credit corporations, 1924–1929*

BALANCE OUTSTANDING DECEMBER 31

Year	Corporation A	Corporation B	Corporation C	Corporation D	Corporation E	Total	Ratio of carry-over to new loans made in same year
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Per cent*
1924		19,175				19,175	3.7
1925	298,829	4,040		14,485	283,248	600,602	28.3
1926	550,584	269,258	(1)	58,706	953,573	1,832,121	35.7
1927	204,112	89,137	38,229	61,155	372,913	765,546	26.2
1928	393,210	83,443	59,915	159,654	491,028	1,187,250	27.7
1929	323,224	123,678	199,333	225,448	367,119	1,238,802	24.6
Total	1,769,959	588,731	297,477	519,448	2,467,881	5,643,496	
Ratio of carry-over to new loans made in same years	*Per cent* 47.7	*Per cent* 6.6	*Per cent* 18.0	*Per cent* 48.6	*Per cent* 53.7		28.2

BALANCE OUTSTANDING THE FOLLOWING SUMMER

	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Per cent*
1924		0					
1925	16,000	0		14,000	225,000	255,000	12.0
1926	175,000	2,196	33,577	50,000	850,000	1,110,773	20.8
1927	75,000	56,388	19,188	14,057	325,000	489,633	16.8
1928	275,000	653	27,869	71,737	437,000	812,259	19.0
1929	175,000	21,827	91,598	70,537	335,000	693,962	13.8
Total	716,000	81,064	172,232	220,331	2,172,000	3,361,627	
Ratio of carry-over to new loans made in same years	*Per cent* 19.3	*Per cent* 0.9	*Per cent* 9.3	*Per cent* 20.6	*Per cent* 47.3		16.6

[1] Unknown.

The lower half of Table 10 consists of actual amounts still outstanding in the following summer for corporations B and C and estimates of loans carried over to the following summer for corporations A, D, and E. These estimates were made by the managers of the corporations and are probably accurate. The average amount of loans carried over to the following summer ranged from 0.9 of 1 per cent of the total loans made in one corporation to 47.3 per cent for another. The corporation with the average carry-over of 47.3 per cent is at present in the process of liquidation.

LOSSES

It has been impossible to obtain comparative data relative to losses. All corporations have carry-over loans. Some have written off part of that carry-over as loss even though they felt certain that the amounts would later be collected. Others have continued to show as carry-over, loans which they knew they could not collect.

At the time that detailed studies were made of five corporations the following conditions appeared to obtain: Corporation 1 had no losses and anticipated none. Corporation 2 had taken a loss of $300 which it hoped to recover. Corporation 3 had written off no losses, but the management realized that large losses would finally have to be taken on some accounts. Corporation 4 had written off all losses, totaling $39,510. Corporation 5 had losses estimated by the Federal intermediate credit bank to be $236,838.

For the last two corporations mentioned above, the losses for all years prior to the date of this study represented 1.4 and 5.2 per cent, respectively, of the amounts originally loaned.

REDISCOUNT RELATIONS WITH THE FEDERAL INTERMEDIATE CREDIT BANKS

To obtain the rediscount privilege, an agricultural credit corporation must make application to the Federal intermediate credit bank of its district. Upon application to the bank an examination of the corporation is made by the officials or a representative of the bank. This examination covers the territory to be served, the legal and financial set-up of the corporation, the amount and source of capital, the character of the management, the relationship with affiliated organizations, and the proposed operations of the corporation.

LINES OF CREDIT AND EXCESS-COLLATERAL REQUIREMENTS

The bank each year determines the line of credit it will extend to the corporation. Under the provisions of the agricultural credits act of 1923, which created the banks, the maximum line of credit possible for any corporation is an amount which, added to the other liabilities of the corporation, equals ten times the paid-in and unimpaired capital and surplus. During the early years of the system, lines of credit approximately as large as that were granted. But experience showed a ratio of 10 to 1 to be too large. In some cases the lines of credit were sharply reduced to as low as 4 to 1 on the unimpaired capital. In other cases the reduction was made much more slowly. At present crop-financing corporations are usually granted lines of credit from two to six times their paid-in and unimpaired capital and surplus.

The ratio for each corporation depends chiefly on the character of the management and the quality of the paper offered to the bank for rediscount. In general, corporations that rediscount livestock paper have been granted a higher ratio than those that rediscount crop-production paper. Some corporations included in this study have suffered at times a sharp decrease in lines of credit because of an impairment of capital as well as on account of the general reduction in ratios granted by the banks.

The actual amount of loans rediscounted is generally less than the line of credit, the latter representing the upper limit. Table 11 indicates for five corporations the relation between the maximum rediscounts each year and the paid-in and unimpaired capital and surplus. Since the figures for capital and surplus as of the date of maximum rediscounts are not available, the capital and surplus as of the end of the year is used. Capital and surplus as of the first of the year would be too small because much new capital stock is sold

during the lending period. Capital stock at the close of the year, however, represents approximately the amount outstanding at the time of the peak lending period. Surplus figures in some cases are higher at the close of the year than in the peak months and in some cases are lower. Thus it is probable that the paid-in and unimpaired capital and surplus as of the end of the year represents fairly well, in most instances, the basis on which the line of credit was granted.

TABLE 11.—*Ratio of maximum amount of rediscounts each year to the paid-in and unimpaired capital and surplus at the close of the year, for five corporations, 1924–1929*

Year	Corporation A	Corporation B	Corporation C [1]	Corporation D	Corporation E
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1924	[2]	3.91	[2]	[2]	[2]
1925	0.92	[3]	[2]	[4]	7.45
1926	8.53	[3]	0.58	2.12	9.03
1927	3.33	3.23	.85	1.64	[3]
1928	3.50	4.80	.78	1.71	[5] 13.74
1929	4.74	5.37	1.57	2.02	[5] 24.31

[1] Corporation does not devote its full capital to the production credit loans.
[2] Corporation not operating.
[3] Data not available.
[4] No rediscounts.
[5] Ratio in excess of 10 because an analysis of paper at the end of the year showed a large impairment of capital.

The Federal intermediate credit banks are dependent on the capital of the rediscounting corporations as a margin for protection against loss on bad paper; consequently they must be assured that the capital will not be dissipated while the corporations are indebted to them. If that capital were invested in loans to farmers, it could easily be lost, leaving the banks with no margin of protection. The general practice of the Federal intermediate credit banks at present is to require that a substantial part of the capital be invested in approved bonds and pledged with the bank as additional collateral. United States bonds and Federal land bank bonds are commonly purchased for that purpose. At the time this practice was adopted many of the corporations had all of their capital invested in unmatured or uncollectible notes of farmers. In several cases the banks took those notes and used them as additional collateral to secure the rediscounts. The Federal intermediate credit banks have not customarily sold the additional collateral pledged with them if the rediscounts were not liquidated each year. In case the bank planned to continue business with the corporation the succeeding season it often retained the additional collateral and asked that the unpaid balance of individual borrowers be renewed and further fortified by new mortgages.

The decision in this matter by the Federal intermediate credit bank is very important to the corporation. If the bank uses the additional collateral to liquidate overdue notes at the end of the season, the corporation is left without collateral to pledge for a line of credit the next season. Therefore, unless the corporation can collect those debts or get new capital, it will suffer a reduction in its line of credit the succeeding season or possibly find itself entirely without rediscount credit.

Of the five corporations of which detailed studies were made prior to 1930, only one had cleaned up its account each year. Another had liquidated its account in all but one year. The three others had not followed this practice either because the Federal intermediate credit banks had not insisted on it or else because the corporations were unable to do so. One of the five corporations has not been able to liquidate its debt to the bank since it opened the account.

VOLUME OF REDISCOUNTING

Total rediscounts by years for each corporation (except three small organizations) are shown in Table 12 and Figure 5. The data represent in most cases the largest month-end balance of the rediscounts account for each season. Since the peak of rediscounts was probably reached on some day of the month other than the last, it is probable that these figures are somewhat understated. Loans rediscounted with the Federal intermediate credit banks reached a peak in 1926 of more than $7,000,000. That year was followed by a considerable recession in volume of business, but of late years the volume has again mounted, reaching a new peak in 1930.

TABLE 12.—*Total rediscounts with Federal intermediate credit banks by 11 corporations, 1924–1930*

[The data in many cases represent the largest month-end balance of the rediscounts account for each season]

Corporation	1924	1925	1926	1927	1928	1929	1930	Total
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A		96, 975	1, 430, 779	586, 237	585, 976	819, 514	920, 486	4, 439, 967
B	440, 000	465, 000	1, 300, 000	875, 000	1, 701, 000	2, 625, 000	[1] 4, 700, 000	12, 106, 000
C	0	0	112, 965	257, 050	238, 324	491, 476	575, 863	1, 675, 678
D		0	112, 645	149, 494	170, 801	225, 609	[1] 250, 000	908, 549
E		1, 331, 000	2, 005, 000	1, 094, 000	880, 000	394, 000	[1] 80, 000	5, 784, 000
F	1, 049, 080	2, 048, 386	2, 465, 867	[1] 615, 000	[1] 485, 000	[1] 400, 000	[1] 400, 000	7, 463, 333
G				68, 985	250, 673	715, 474	[2]	1, 035, 132
H [1]				29, 340	49, 000	75, 000	[2]	153, 340
I						10, 580	55, 385	65, 965
J [1]			43, 000	68, 000	[2]	[2]	[2]	111, 000
K [1]							270, 000	270, 000
Total	1, 489, 080	3, 941, 361	7, 470, 256	3, 743, 106	4, 360, 774	5, 756, 653	7, 251, 734	34, 012, 964

[1] Estimated. [2] Corporation not operating.

The agricultural credit corporations organized by the cotton cooperative associations have been responsible for a large part of the discount credit extended by the Federal intermediate credit banks in various States and sections of the country. Table 13 shows the ratio of the discounts for these corporations to the total discounts for crop production by the same banks and to the total discounts for all purposes. The corporations in Mississippi that are included in this study accounted for 98 per cent of the total amount granted in that State in 1929 and 1930 by the Federal intermediate credit bank of the district. In California, on the other hand, the corporation furnished less than 1 per cent. For all of the States listed the corporations mentioned furnished about one-half of the production credit and about one-fifth of all discounts granted by the Federal intermediate credit banks. In the States that are primarily cotton producers the corporations mentioned furnished one-third

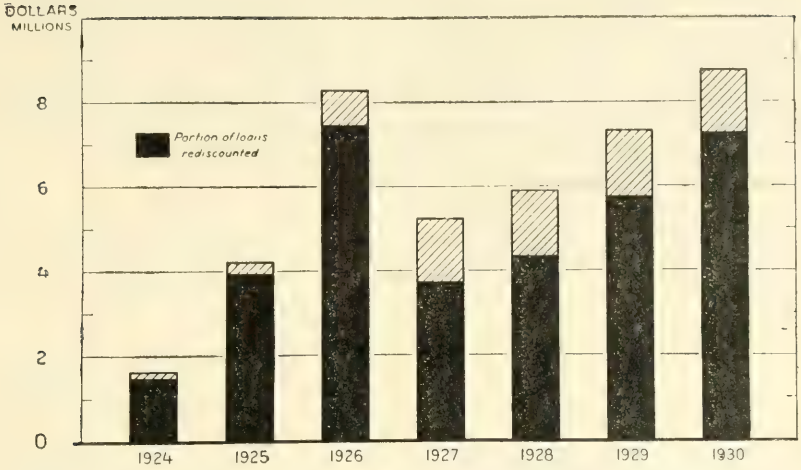

FIGURE 5.—TOTAL PRODUCTION LOANS AND REDISCOUNTS OF AGRICULTURAL CREDIT CORPORATIONS ORGANIZED BY COTTON COOPERATIVE MARKETING ASSOCIATIONS

The increase in volume of loans has been relatively uniform, except in 1926. Rediscounted loans in the last half of the period have formed a smaller portion of the total than in earlier years.

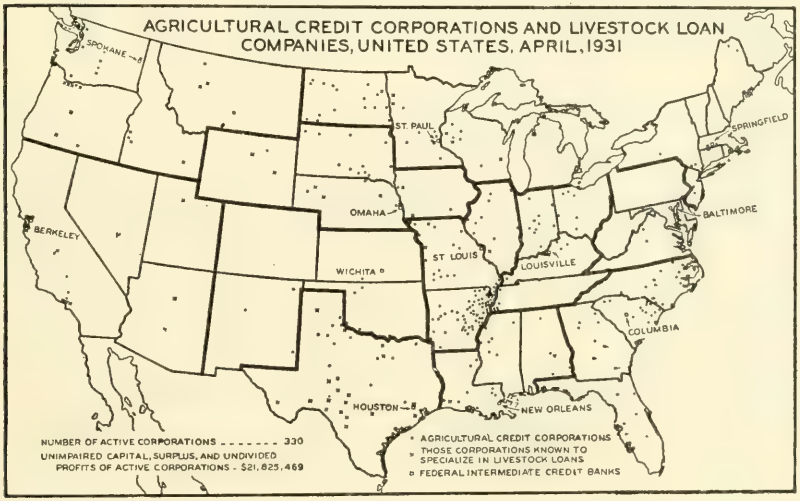

FIGURE 6.—Agricultural credit corporations and livestock loan companies appear to have their most extensive development in Arkansas. Other areas such as the Southeastern States, the North Central States, and Texas appear to have a considerable number of such organizations. An entirely different situation might appear, however, if the volume of business were considered. The volume of original discounts closed by the Federal intermediate credit banks in 1930 was largest for Texas, and next largest for California, Louisiana, and Mississippi in the order named

or more of the crop-production credit and about one-sixth of all credit granted by the banks. Finally, the corporations included in this study rediscounted in 1929 and 1930 approximately one-fourth of the crop-production credit loans advanced by the 12 intermediate credit banks of the country and approximately one-tenth of the total discount credit extended for all purposes. It is obvious, therefore, that although in number the credit corporations organized by the cotton cooperative associations represent a small proportion of the total (fig. 6) they have accounted for a large part of the business of the Federal intermediate credit system.

TABLE 13.—*Ratio of discounts of the Federal intermediate credit banks for agricultural credit corporations organized by the cotton cooperative marketing associations to all discounts for crop production and to all discounts,*[1] *1929 and 1930*

Territory	Percentage of discounts for crop production purposes		Percentage of all discounts	
	1929	1930	1929	1930
	Per cent	*Per cent*	*Per cent*	*Per cent*
Georgia	51	55	51	55
Alabama [2]	54	38	51	32
Mississippi	99	98	99	98
Texas and New Mexico	91	86	3	4
South Carolina	8	0	8	0
North Carolina [2]	20	21	20	21
California	.5	2	.2	.6
Tennessee	99		94	
Tennessee, Arkansas, and Missouri		18		12
All States listed	50	51	18	21
All cotton States except Florida, Virginia, and Arizona	33	39	15	18
United States	27	27	9	10

[1] Original discounts. [2] Estimated.

Table 14 shows the ratio of rediscounts to loans. The first part of the table shows the ratio at the peak of lending and is obtained by dividing the total amount of rediscounts for the year by the total amount of loans (both new and carry-over). The second part of the table is the average ratio for the year. It is obtained by using the month-end balances of the loan and the rediscount accounts. The sum of the 12 month-end balances for the rediscount account each year is divided by the sum of the 12 month-end balances of the loan account. This ratio is in reality the average of the monthly ratios of rediscounts to loans, weighted by the balance of the loan account each month. As a weighted average it is more significant than a simple average of the monthly ratios would be.

TABLE 14.—*Ratio of rediscounts to production credit loans, in specified corporations, 1924–1929*

AS OF PEAK PERIOD

Year	Corporation A	Corporation B	Corporation C	Corporation D	Corporation E	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1924	(1)	85.8	(1)	(1)	(1)	85.8
1925	97.3	75.4	(1)	(2)	96.4	89.7
1926	92.9	81.6	58.2	85.3	92.8	82.2
1927	92.1	65.4	51.9	73.0	77.0	71.9
1928	77.0	79.5	45.5	62.1	79.3	68.7
1929	75.2	97.5	66.9	57.1	63.5	72.0
Average	86.9	80.9	55.6	69.4	81.8	76.2

AVERAGE FOR THE YEAR

1924	(1)	78.1	(1)	(1)		
1925	26.5	50.4	(1)	(2)		
1926	80.8	67.6	40.8	79.5		
1927	69.9	57.6	45.4	53.5		
1928	64.6	71.3	43.7	55.2		
1929	67.3	74.8	58.3	46.7		
Average	61.8	66.6	47.0	58.7		

[1] Corporation not operating. [2] Small volume of loans with no rediscounts.

The ratio of rediscounts to loans at the peak of lending activities averaged 76.2 per cent and ranged from 45.5 to 97.5 per cent. In other words, these corporations during peak periods were borrowing from the Federal intermediate credit banks about three-fourths of the money they loaned and furnishing the other one-fourth out of their capital or out of funds borrowed from the cotton associations or some other source. The lowest average ratio for any corporation was 55.6 per cent and the highest was 86.9. The low ratio of 55.6 per cent may be explained by the fact that that particular corporation has had a large capital from which to make loans and the further fact that it has borrowed funds from the cotton association during the heavy lending period. Yearly averages for all corporations combined show in general a trend downward from ratios of almost 90 per cent in the early years to ratios of approximately 70 per cent in the later years.

Average ratios for the year as calculated from month-end balances of accounts are available for only four of the corporations. These are much lower than the ratios in the peak periods. In fact the average amount rediscounted throughout the year represents approximately three-fifths of the total instead of three-fourths as shown by the ratio for the peak periods.

There are very few alternate sources of funds for the corporations. At certain times in the year when the funds of the cotton associations have not been in use, the corporations in a few cases have been able to borrow them. At various times some of the corporations have been able to borrow small amounts from commercial banks by pledging some of the notes they held in their portfolios. In general, however, the corporations have depended largely on the Federal intermediate credit banks for their loanable funds.

REDISCOUNT RATES AND MARGINS ALLOWED

Rediscount rates charged by the banks have varied from 4 to 6 per cent. (Fig. 7.) The rediscount rate depends on the interest rate at which the bank has been able to sell its own debentures, for the banks are not permitted by law to charge a rate of discount more than 1 per cent in excess of the interest rate on their most recent issue of debentures. The framers of the law apparently felt that 1 per cent would be a sufficient margin to cover the cost of operation and any losses that might occur. It is doubtful, however, if the 1 per cent margin is sufficient for this purpose in the case of loans rediscounted for agricultural credit corporations. Were it not for the commodity loans to cooperative associations, with the same spread for earnings

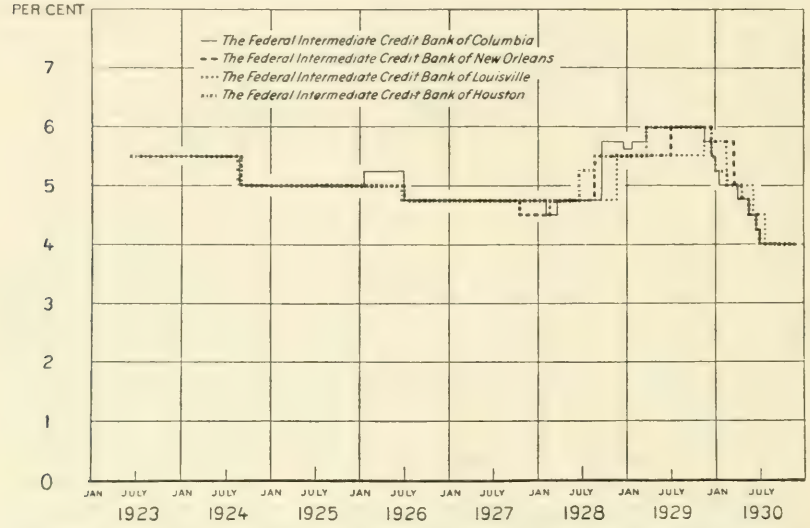
PER CENT
7
6
5
4
3
2
1
0
The Federal Intermediate Credit Bank of Columbia
The Federal Intermediate Credit Bank of New Orleans
The Federal Intermediate Credit Bank of Louisville
The Federal Intermediate Credit Bank of Houston
JAN JULY JAN JULY JAN JULY JAN JULY JAN JULY JAN JULY JAN JULY JAN JULY
1923 1924 1925 1926 1927 1928 1929 1930

FIGURE 7.—RATES OF DISCOUNT FROM THE DATE OF ORGANIZATION TO DECEMBER 31, 1930, OF FOUR FEDERAL INTERMEDIATE CREDIT BANKS WHICH DISCOUNT PAPER OF COTTON FARMERS

Rates of discount charged by the four Federal intermediate credit banks serving most of the cotton-growing States have varied from 4 to 6 per cent. Rates of 4¾ or 5 per cent were prevalent during most of the years. (Data furnished by Federal Farm Loan Board.)

the banks might be unable to operate at a profit. Such loans are generally large and require less expense per dollar for service than do most rediscounts. The somewhat larger profits that the banks make on their commodity loans tend to offset the heavier expense on the rediscount of farmers' notes.

At present the banks are not permitted to rediscount paper on which the rate charged the borrower is more than 3 per cent higher than the rediscount rate of the bank. When the agricultural credits act of 1923 was passed the margin was set at 1½ per cent, but the Federal Farm Loan Board was given power to change it. Several changes have since been made. On January 7, 1924, the spread permitted on livestock loans was increased to 2 per cent and on January 31, 1925, to 2½ per cent. On January 29, 1927, the spread was increased from 1½ per cent to 2 per cent on general agricultural

paper. The margin was increased again on April 9, 1931, to 3 per cent on all types of paper.

THE BANKS' EXAMINATION OF LOANS

The Federal intermediate credit banks make an analysis of all loans offered for rediscount. In this examination they are seriously handicapped by not having a personal acquaintance with the farmers who apply for loans; they must depend upon the opinions of others to evaluate the personal characteristics of the borrower. As a result the banks must base their analysis largely upon the financial statement of the borrower and other quantitative data obtained by the corporation. The lack of personal relations is a serious handicap to the bank and to the applicant who shows a poor financial statement but who nevertheless is a good personal risk.

CAUSES OF DISSATISFACTION

There has been some dissatisfaction with the Federal intermediate credit banks on the part of these finance corporations. In the early years many corporation officials felt that their corporations should be entitled to a line of credit equal to the maximum permitted under the law and that any reduction in the ratio was unfair and a reflection upon their organizations. Another source of trouble has been the demand of some banks for better security and the refusal to accept loans without such security. Officers of the finance corporations contended that since they were acquainted with the borrower and knew the personal risk involved they were able to judge certain loans better than the banks, which must depend primarily upon a quantitative analysis of the application. Undoubtedly there was some merit in their contention. On the other hand, the banks in the early years had had experience with loans granted at the discretion of officers of credit corporations and in many cases had encountered difficulty in collecting them.

Still another source of dissatisfaction between the banks and the corporations was the fact that the banks have at all times required that the legal papers with regard to loans be flawless. Since they did not know the borrower personally and could not depend on his moral character it was necessary that they leave no loophole to enable him to avoid paying the loan. At present, most of the misunderstandings and difficulties have been fairly well adjusted, and the relationships for the most part are decidedly friendly.

COSTS OF LOANS TO THE BORROWER

One of the purposes of the cooperatives in organizing affiliated agricultural credit corporations was to make cheaper credit available to members. The cost of credit for producing cotton is well known to be high; many have considered it excessive. What has been the experience of these credit corporations in reducing the cost of credit to borrowers?

Legislation by the States to limit the rates of interest that may be charged have led to various subterfuges such as additional fees, flat charges rather than annual rates of interest, and the like. Usury

laws have also tended to force the financing of the farmer from the banker to the merchant, who may charge what he chooses for interest by merely adding the charge to the price of his goods. Thus, in any analysis of the cost of credit, interest rates are not the only costs to be included. This is as true of credit obtained through an agricultural credit corporation as of credit obtained elsewhere. The following analysis of costs to the borrower takes into account not only the interest charge but also numerous other costs.

RATE OF INTEREST

Figure 7 indicates the rates that have been charged in various years by the four banks that serve most of the cotton States. If the margin allowed agricultural credit corporations of 1½, 2, or 3 per cent, is added to the bank rates, it is possible to get an approximation of the discount rates paid in past years by the borrowers. One corporation, however, has not always taken the full spread allowed.

Table 15 shows the average discount rates that have been charged during the various years by four of the corporations. The high rates in 1929 reflect the general high cost of credit throughout the country. Rates decreased again in 1930 and the first half of 1931.

TABLE 15.—*Approximate rates of discount charged by four agricultural credit corporations, 1924–1929*

Year	Corporation A	Corporation B	Corporation C	Corporation E	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1924		6.25			6.25
1925	6.50	5.75		6.50	6.25
1926	6.75	6.00	6.50	6.75	6.50
1927	6.75	5.88	6.75	6.75	6.53
1928	6.62	5.50	6.75	6.62	6.37
1929	7.88	5.75	7.88	7.88	7.35
Average	6.90	5.86	6.97	6.90	6.60

It should be remembered that the rates shown in Table 15 are discount and not interest rates. A rate used for discount charged in advance is always more costly to the borrower than the same rate used for an interest charge at maturity of the note. Thus 7 per cent discount on a $100 note for one year means the payment of $7 for the use of $93 for 1 year or a rate of interest of 7.53 per cent. For rates below 7 per cent, the difference between the discount and real interest rate is less than 0.53 per cent and for rates above that it is more. Moreover, the difference on an annual basis when loans are for periods of less than one year would be smaller than if the loans were for a whole year as shown above, because the payment of the discount is for a shorter time in advance. Table 16 shows interest rates equivalent to customary discount rates for typical periods.

TABLE 16.—*Interest rates equivalent to specified discount rates*

Annual discount rate	Equivalent annual interest rate on loans of—		
	1 year	9 months	6 months
Per cent	*Per cent*	*Per cent*	*Per cent*
6	6.38	[1] 6.28	[1] 6.19
7	7.53	[1] 7.39	[1] 7.25
8	8.70	[1] 8.51	[1] 8.33

[1] Sometimes referred to as nominal rates of interest. The effective rates, the rates based on compounding interest only once a year, would be as follows: Nine months, 6.33, 7.46, and 8.60; six months, 6.28, 7.39, and 8.51.

FACTORS MODIFYING RATE OF INTEREST IN ASCERTAINING COST TO BORROWER

Several modifications of the discount rates must be taken into account in ascertaining the actual cost to the borrower. These corporations advance the funds to many of their borrowers in installments. With some corporations the practice is almost universal; with others it is used only in a minority of cases. Two of the five corporations studied have charged the borrower for the money from the exact date of each installment advanced him. The other three have charged discount on the whole sum from the date of discounting the note; hence, for these three corporations the real cost to the borrower has been greater than the stated rate. Two of these three corporations were forced to follow this policy; the Federal intermediate credit bank with which they discounted paper did not itself advance the loan in installments, but advanced the total sum to the agricultural credit corporations at the time of rediscount without regard to the installments. Hence it charged the corporations on the full sum from the date of rediscount.

As the corporations kept the funds in a city bank until the installments were due and received very little if any interest thereon, they found it necessary to charge the borrowers for the full period of the loan. The fact that the borrower was required to pay interest on the whole loan from the date of discount regardless of the fact that he received it in installments made the actual rate of discount higher for him than the quoted rate. On the other hand, this extra cost to the borrower was not such a burden or so unfair as it might seem at first thought. If all of the funds were made available to him at the date of discount, he himself would have deposited them in his local bank, probably without interest. It cost him no more to have the funds in a city bank to the credit of an agricultural finance corporation than in a local bank to his own credit.

In finding the true cost of money to the borrower, the matter of refunding of interest on loans paid in full or in part before maturity must be considered. The same two corporations that charge interest only from the date of each installment also refund interest to the borrowers for the period from each payment on the loan until maturity. Moreover, these corporations calculate the interest to the exact day on every payment applied to the loan. The other corporations have not done so well by the borrower.

It has been the practice of one of the Federal intermediate credit banks in refunding discount on payments before maturity to refund the discount at a rate 1 per cent below the rate on its debentures, and not at the rate charged by the bank. It should be remembered that the bank's charges are 1 per cent in excess of the rate on its debentures. Hence if the rate on the bank's debentures has not changed within the period of the loan, it refunds discount on prepayments at a rate 2 per cent below the rate paid. Officials of that bank feel that they have gone to the expense of placing the loan and hence have earned their margin of 1 per cent interest for the full period of the loan. Moreover, since the maturities of the bank's debentures are based on the maturities of the loans it has made, the bank probably has to relend the money and contends that it is entitled to another 1 per cent of the loan from the date of payment to maturity.

Following the same line of reasoning, the corporations feel that they have earned the full margin of income allowed to them for the full period of the loan until maturity and do not see fit to refund to the borrower anything more than the bank refunds to them. Thus the borrower, last in the line, is refunded discount for the unused portion of the term of the loan at a rate which has often been 4 per cent below the rate which he has paid for the money.

Assume, for instance, that the borrower has paid 7 per cent for the money, out of which 2 per cent was the corporation's margin and 1 per cent the bank's margin. If there had been no changes in the rates on debentures of the bank, he would have received a refund of discount for the period from the date of repayment until maturity at 3 per cent. He thus paid 7 per cent for the time he actually had the money and in addition 4 per cent from the date of actual repayment to the date of the maturity of the note. Possibly the borrower is lucky to receive any allowance for payment before maturity. Many of the local banks make no refund whatsoever. Nevertheless, this practice makes the actual rate that the borrower pays somewhat higher than the quoted rate.

Two of the corporations are known to make additional charges in the form of fees. These fees are small, being in one case $3 flat charge and in the other $1 plus 10 cents for every $100 of the loan or fraction thereof. In some cases when it has been necessary to send a special investigator to appraise the security offered for the loan, the cost has been assessed against the borrower.

The borrower is always expected to pay the cost of searching the county records to show what prior liens, if any, exist, and to pay for recording and releasing mortgages or other liens. Generally the borrower himself employs and pays someone to search the records and pays recording fees. In some cases, however, the corporation has this work done and deducts the charges from the face of the loan. By employing someone to take care of all of its work in a county the corporation is often able to have records searched at a much lower cost than the individual would have to pay. For large loans the expenses of recording and searching of records do not add materially to the cost on a percentage basis. But for a loan of $500, which is about the median-size loan, the typical charge for the service of from $2 to $5 is significant in its effect on the rate of interest. Charges

as high as $10 have often been made for searching the records. Such a charge would add as much as 2 per cent to the interest rate on a $500 loan for 1 year or 4 per cent if the loan was for only 6 months.

No estimate of the cost of the loan to the borrower would be complete without taking into account the cost to the borrower of owning stock of the corporation, a practice that is now required by all but one organization. The corporations, with one exception, have not paid dividends on their stock. If the borrower must own nondividend-paying stock for the privilege of obtaining the loan, the loss of return on investment is a proper charge to the cost of that loan.

Assuming that investments in stock should yield 7 per cent (a rate only slightly above the average rate paid as interest by borrowers on their loans) and further assuming that the borrower must take stock equal to 10 per cent of the loan, the loss in dividends would be 7 per cent of 10 per cent of the loan or 0.7 per cent. This is an addition to the interest rate on the loan. Moreover, if the stock of the corporation depreciates in value, that loss in value should also be added to the cost by distributing it over the number of years in which loans were obtained. This is a large item in the case of some corporations whose stock has lost its entire value.

FINAL COST TO THE BORROWER

Table 17 represents an attempt to estimate the cost to the borrower of a typical loan on an annual interest rate basis. The typical loan is taken as one of $500 since that is close to the median size, and 7 per cent rate of discount is selected as being near the average. The final estimate amounts to about 10 per cent. Adjustments must be added to these rates if the loan is made in installments or paid before maturity without a proportional reduction in interest. Additions must be made if the stock of the corporation owned by the borrower has depreciated in value.

TABLE 17.—*Estimated cost, on an annual interest rate basis of a typical loan ($500 at 7 per cent) for designated periods*

Item	12-month note	9-month note	6-month note
	Per cent	*Per cent*	*Per cent*
Rate of annual interest equivalent to 7 per cent annual discount	7.53	7.39	7.25
$4-fees for examining title and recording liens	.80	1.06	1.60
Subtotal	8.33	8.45	8.85
Seven per cent return sacrificed annually on investment in stock of the corporation	.70	.93	1.40
Subtotal	9.03	9.38	10.25
$1.50 fee for application	.30	.40	.60
Total	9.33	9.78	10.85

The cost of loans through these credit corporations compares favorably with the cost through other agencies. Table 2 indicates average costs of cash credit to cotton growers, ranging from 7.7 to 11.5 per cent. Much of this cash credit was obtained from banks. Although farmers with good credit often can borrow at their local

banks for 6, 7, or 8 per cent per annum, banks in many sections make flat charges, sometimes as high as 10 per cent, despite the fact that the loans are of less than a year's duration. For the corporations that have not required the borrower to purchase capital stock, and for those that have, but have paid dividends thereon, the costs of loans compare favorably with bank rates.

The cost of loans through the credit corporations has clearly been much lower than the customary charges for merchant credit. (Table 2.) As a rule, however, the borrower from a credit corporation is a better risk than the average farmer who uses merchant credit. Those farmers who are obtaining their credit at high rates from merchants and who could qualify for a loan from some credit corporation would find such a change a real economy.

In appraising these organizations on the basis of the cost of loans to the borrower, it should be kept in mind that the loans are seasonal and of less than a year's duration. In addition, they often are small and hazardous. All of these factors lead toward high costs of operation, which in turn are reflected in high charges to the borrower, especially when stated on an annual interest basis. All of these characteristics except the one of seasonality are found also in loans to consumers in industrial centers and contribute to the necessity for charging a high rate of interest, as evidenced by Table 18.

TABLE 18.—*Cost on a per annum basis of loans from various agencies extending personal credit in urban areas*

[Data obtained from Financing the Consumer, by Evans Clark, 1930. p. 119]

Agency	Usual charge	Range of charges
	Per cent	*Per cent*
Credit unions	12.0	6.0–18.0
Personal loan departments	18.1	9.4–22.6
Industrial banks	17.3	17.3–34.4
Remedial loan societies	26.9	12.0–36.0
Axias	28.5	
Pawnbrokers	36.0	12.0–120.0
Personal finance companies	42.0	30.0–42.0

The reasonable, if not low, rates charged by agricultural credit corporations must be attributed in large part to the efforts of the Federal Government to aid farmers. It established the Federal intermediate credit banks and contributed all of their capital; it supervises them and grants them the privilege of issuing tax-free debentures. The exemption of the banks' debentures from both Federal and State taxation enables them to be sold to the public at a rate of interest lower than would otherwise be possible. The extent to which the securities sell at lower interest rates because of the tax-free feature depends on the rates of tax at the time. A study of interest rates from 1918 to 1926 indicates an average difference in yield rates, due to tax exemption, of 0.85 per cent.[5] Because of the decrease since then in the surtax rates of the Federal income tax, the difference is much less at present.

[5] ROWE, W. H. THE BURDEN OF TAX EXEMPTION OF GOVERNMENT BONDS. Amer. Econ. Rev. 16: [653]–659. 1926.

INCOME, COSTS, AND PROFITS

One of the problems that agricultural credit corporations throughout the country have had to face is the inadequacy of income and profits. Until 1927 the Federal intermediate credit banks were permitted to rediscount crop paper for the corporations only if the rate of discount charged borrowers was not more than 1½ per cent in excess of the rediscount rate charged by the bank. From 1927 to 1931, a 2 per cent margin on crop-production loans was allowed. In most cases this margin has not proved sufficient for the corporations to pay expenses and absorb losses. The corporations affiliated with the cotton marketing associations were organized for service, and in most cases they have not been expected to earn a profit for the stockholders but it has been hoped that they would at least be self-supporting.

OPERATING STATEMENTS

Complete data relative to income and operating expenses are available for four corporations only. Limited data covering income and interest expense are available for a fifth. Table 19 contains a summary operating statement of each of these corporations for the full period of its life and a combined statement for all corporations for all years. The table also shows the expenses and profits in percentage of total income.

TABLE 19.—*Operating statements for five agricultural credit corporations covering period from date of organization to the close of the 1929 calendar or fiscal year* [1]

Item	Corporation A (5 years)		Corporation B (5 years)		Corporation C (4 years)		Corporation D (5 years)	
	Dollars	*Percent*	*Dollars*	*Percent*	*Dollars*	*Percent*	*Dollars*	*Per cent*
Income	249,095	100.0	158,564	100.0	111,757	100.0	60,182	100.0
Interest cost	137,487	55.2	75,932	47.9	32,780	29.3	28,384	47.2
Gross profits	111,608	44.8	82,632	52.1	78,977	70.7	31,798	52.8
Other operating expense	89,886	36.1			75,111	67.2	33,365	55.4
Net operating profit	21,722	8.7			3,866	3.5	−1,567	−2.6
Other adjustments [1]	1,611	.7			−367	−.4		
Net profit or loss [1]	23,333	9.4			3,499	3.1	−1,567	−2.6

Item	Corporation E (5 years)		Total		Total of corporations A, C, D, E	
	Dollars	*Percent*	*Dollars*	*Percent*	*Dollars*	*Per cent*
Income	283,498	100.0	863,096	100.0	704,532	100.0
Interest cost	172,069	60.7	446,652	51.7	370,720	52.6
Gross profits	111,429	39.3	416,444	48.3	333,812	47.4
Other operating expense	127,600	45.0			325,962	46.3
Net operating profit	−16,171	−5.7			7,850	1.1
Other adjustments [1]	−7,934	−2.8			−6,690	−.9
Net profit or loss [1]	−24,105	−8.5			1,160	.2

[1] This table does not include the losses incurred on loans by some of the corporations.

Income and expense figures available for four corporations have been classified also on the basis of years and are shown in Table 20. Being a combined statement of profit and loss this table shows cer-

tain trends in the industry as a whole. Both income and interest costs reached their high point in 1926. Profits from operations were earned in 1925 and 1926; in 1928 interest and operating expenses about equaled the income. Losses were sustained on operations in 1927 and 1929.

It is probable, however, that these totals are too greatly influenced by figures of individual corporations for many general conclusions to be drawn from them. Undoubtedly the profits shown from operations in 1925 and 1926 were partly due to handling a large volume of business without sufficient servicing of the loans. The year 1927 was one of retrenchment. New loans were restricted, and old ones were collected, with the result that the earnings from interest were small and expenses were high.

TABLE 20.—*Summary of the operating statements of four agricultural credit corporations, 1925–1929*

Item	1925		1926		1927	
	Amount	Percentage of total income	Amount	Percentage of total income	Amount	Percentage of total income
	Dollars	*Per cent*	*Dollars*	*Per cent*	*Dollars*	*Per cent*
Income	76,338	100.0	215,824	100.0	153,060	100.0
Interest costs	47,077	61.7	129,905	60.2	73,967	48.3
Gross profit	29,261	38.3	85,919	39.8	79,093	51.7
Other operating expense	15,968	20.9	66,594	30.9	96,873	63.3
Net operating profit	13,293	17.4	19,325	9.0	−17,780	−11.6
Other adjustments	−4,071	−5.3	−10,424	−4.8	7,143	4.7
Net profit or loss	9,222	12.1	8,901	4.1	−10,637	−6.9

Item	1928		1929		Total [1]	
	Amount	Percentage of total income	Amount	Percentage of total income	Amount	Percentage of total income
	Dollars	*Per cent*	*Dollars*	*Per cent*	*Dollars*	*Per cent*
Income	142,695	100.0	134,248	100.0	722,165	100.0
Interest costs	63,435	44.5	61,396	45.7	375,780	52.0
Gross profit	79,260	55.5	72,852	54.3	346,385	48.0
Other operating expense	79,172	55.5	76,242	56.8	334,849	46.4
Net operating profit	88	.1	−3,390	−2.5	11,536	1.6
Other adjustments	−11,904	−8.3	12,566	9.4	−6,690	−.9
Net profit or loss	−11,816	−8.3	9,176	6.8	4,846	.7

[1] Total figures do not exactly agree with those of Table 19 because estimates were necessary to change the basis of the statements of one corporation from a fiscal to a calendar year.

Expenses for each corporation have been classified in five groups and are shown for each of the four corporations in Table 21 in which are also given the percentages each group of expenses constitutes of the total expenses and of the total income. Salaries were by far the

largest class, and traveling or field expense, the second largest item. Office expenses were the third in size, but of much less importance than salaries or traveling expenses. Taxes, Government fees, and miscellaneous expenses were of relatively small importance. The expenses, exclusive of interest costs, absorbed 46.3 per cent of the income.

TABLE 21.—*A classification of operating expenses, other than interest costs, for four corporations from the date of organization of each to the close of the 1929 calendar or fiscal year*[1]

Item	Corporation A			Corporation C			Corporation D		
	Amt.	Percentage of total		Amt.	Percentage of total		Amt.	Percentage of total	
		Expense	Income		Expense	Income		Expense	Income
	Dollars	*P. ct.*	*P. ct.*	*Dollars*	*P. ct.*	*P. ct.*	*Dollars*	*P. ct.*	*P. ct.*
Salaries	47,798	53.2	19.2	59,633	79.4	53.3	25,528	76.5	42.4
Traveling and other field expense	25,876	28.8	10.4	9,479	12.6	8.5	3,312	9.9	5.5
Office expense	9,770	10.9	3.9	3,351	4.5	3.0	1,933	5.8	3.2
Taxes and Government fees	216	.2	.1	1,234	1.6	1.1	725	2.2	1.2
Miscellaneous expense	6,226	6.9	2.5	1,414	1.9	1.3	1,867	5.6	3.1
Total	89,886	100.0	36.1	75,111	100.0	67.2	33,365	100.0	55.4

Item	Corporation E			Total		
	Amount	Percentage of total		Amount	Percentage of total	
		Expense	Income		Expense	Income
	Dollars	*P. ct.*	*P. ct.*	*Dollars*	*P. ct.*	*P. ct.*
Salaries	75,273	59.0	26.5	208,232	63.9	29.6
Traveling and other field expense	25,543	20.0	9.0	64,210	19.7	9.1
Office expense	11,509	9.0	4.1	26,563	8.1	3.8
Taxes and Government fees	3,105	2.4	1.1	5,280	1.6	.7
Miscellaneous expense	12,170	9.6	4.3	21,677	6.7	3.1
Total	127,600	100.0	45.0	325,962	100.0	46.3

[1] This table is a supporting schedule for the statements shown in Table 19.

OPERATING FIGURES PER LOAN AND PER DOLLAR OF LOAN

The difficulties of the corporations in earning a satisfactory income become more apparent when the figures for income, costs, and profits are examined in terms of averages per loan and per dollar of loan. Table 22 shows the average income, interest paid, expenses, and profits per loan and per dollar of loan. The income per loan is dependent, of course, on the size of the loan as well as the rate. This fact explains very largely why the average income per loan for one corporation is $36 and for another is $328. Average figures for income, interest cost, expenses, and profits per dollar of loan are also significant.

TABLE 22.—*Average income, costs, and profits for five corporations*

PER LOAN

Corporation	Years included	Income	Interest costs	Excess of income over interest costs	Operating expense	Operating profit	Net profit or loss
	Number	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A	4	53	30	23	19	4	4
B	5	328	157	171			
C	4	75	22	53	50	3	2
D	5	92	43	49	51	−2	−2
E	5	36	22	14	16	−2	−3
Average:							
5 corporations		57	30	27			
4 corporations		48	26	22	22	(1)	(1)

PER DOLLAR OF LOAN

A	4	$0.0575	$0.0326	$0.0249	$0.0209	$0.0040	$0.0043
B	5	.0256	.0122	.0134			
C	4	.0574	.0168	.0406	.0386	.0020	.0018
D	5	.0576	.0272	.0304	.0319	−.0015	−.0015
E	5	.0424	.0257	.0167	.0191	−.0024	−.0036
Average:							
5 corporations		.0425	.0221	.0204			
4 corporations		.0501	.0266	.0235	.0234	.0001	.0003

[1] Less than 50 cents profit.

REASONS FOR SMALL PROFITS

One of the principal causes of the difficulties encountered by these agricultural credit corporations in making a profit or at least avoiding a loss is the seasonal character of the loans. Advances are started in the late winter or early spring; they rise to a peak in August, and are largely liquidated by the end of October or November. (Fig. 8.) The average annual earning period of the loans is from 6 to 7 months as shown in the following tabulation:

1925	6.1
1926	6.8
1927	7.1
1928	6.5
1929	6.5
1930	6.9
Average	6.65

This estimate is obtained by an analysis of the area under the curve in Figure 8. Its accuracy is supported by the results of other studies made in the cotton States. Of those studies, four show the average term of loans for growing the crop. These were found to be 6.8, 7.0, 7.4, and 6.8 months, respectively.

If interest is charged only for the time during which the loans are outstanding, the income of the corporation is limited to about one-half of what it would be were it able to maintain a constant volume of business equal to its full line of rediscount credit. Expenses, on the other hand, are but little less than would be the case if the loan volume were at a maximum level throughout the year. This is partly because it is desirable to maintain a permanent staff, and hence, salaries, the largest item of expense, can not be reduced during the

winter months. In fact, there are only one or two months during the year when the force is not busy either with collections or the making of new loans.

The fact that profits are small may also be attributed to the high costs of operating over a wide territory. Most of the corporations included in this study operate throughout a whole State, and the loans are often widely scattered. It is not uncommon to find only one loan in a county. Under these conditions, the expense of providing even a minimum amount of supervision over the loans is excessive. The manager himself is not able to cover the territory, and a field staff must be employed. Automobiles must be provided and maintained, and living expenses must be paid while the field men are away from home. Long-distance telephone calls are often necessary for the

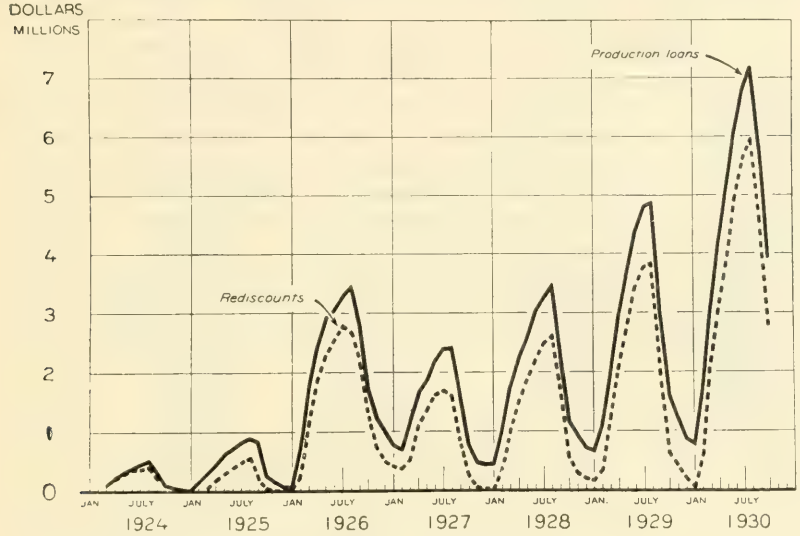

FIGURE 8.—PRODUCTION LOANS AND REDISCOUNTS FOR FOUR AGRICULTURAL CREDIT CORPORATIONS

The shape of the curves indicates the extreme seasonal character of the business. Loans start in the late winter or early spring, rise to a peak in August, and are largely liquidated by the end of October or November. (Data on which these curves are based consist of the month-end balances of the loan and the rediscount accounts.)

field force to keep in touch with the corporation office. Because of the scattered character of the business, much correspondence is necessary; a sample of 12 loans of one corporation indicated an average of 24 pieces of correspondence per loan. Excessive correspondence means a large outlay for stenographic service and postage.

Another factor contributing to the scarcity of profits has been the small size of the loans. Table 22 indicates that for four corporations, in which the average size of loan was $965 and the median size was $494, the excess of income over interest costs per loan was $22, whereas for a fifth corporation whose loans averaged $13,457, the excess of income over interest cost was $171 per loan. Since the cost of making and servicing a small loan is little if any less than the cost for a large loan it is obvious that the small size of loans constitutes a real handicap.

One of the most important causes of the unprofitable showing made by the corporations has been the inadequacy of operating margins on rediscounted loans. If reference is made to Table 22, it may be observed that the average cost per dollar of loan, exclusive of interest costs for four corporations, was 2.34 cents, whereas the income from rediscounted loans under the 2 per cent spread effective until April, 1931, was as much as 2 cents only if the loan had been outstanding the full year.[6] Actually the loans were outstanding only about seven months. It is obvious that in the case of those corporations the income from rediscounted loans was insufficient to meet the operating expenses. It was only through the income from loans not rediscounted on which the corporation earned the full interest collected that the corporations were able to come through the years without a large operating deficit.

COMPARISON WITH EARNINGS AND EXPENSES OF BANKS

The insufficiency of the 1½ per cent and the 2 per cent spread in earnings may be further shown by a comparison of the earnings and expenses of these corporations with those of commercial banks. A comparison was made of the operating ratios of the corporations, those of all member banks in the Federal reserve system, and those of national banks outside of reserve cities in the same four States as these agricultural credit corporations.[7] This latter group of banks operates under conditions similar to the conditions under which the credit corporations operate. Table 23 and Figure 9 show a comparison of the interest costs, operating expenses, and profits of these banks and the credit corporations, expressed as percentages of total income.

TABLE 23.—*A comparison of the operating results of banks and agricultural credit corporations*

[Data for the banks were obtained from the Federal Reserve Bulletin for July, 1930, and the Report of the Comptroller of Currency for 1929]

Item	Member banks, Federal reserve system, 1929		National banks outside of reserve cities in the same four States as the credit corporations, 1929		Four agricultural credit corporations, 1925–1929			
					Actual		Estimated for 1 per cent additional margin of income	
	1,000 dollars	*Per cent*	*1,000 dollars*	*Per cent*	*Dollars*	*Per cent*	*Dollars*	*Per cent*
Income	2,474,099	100.0	58,080	100.0	704,532	100.0	784,803	100.0
Interest costs	823,525	33.3	14,612	25.2	370,720	52.6	370,720	47.2
Gross profit	1,650,574	66.7	43,468	74.8	333,812	47.4	414,083	52.8
Other operating expenses	860,195	34.8	26,109	44.9	325,962	46.3	325,962	41.5
Net operating profit	790,379	31.9	17,359	29.9	7,851	1.1	88,121	11.2
Net adjustments	−233,865	−9.4	−6,937	−11.9	−6,690	−.9	−6,690	−.9
Net profit[a]	556,514	22.5	10,422	17.9	1,161	.2	81,431	10.4

[a] Reliance should not be placed upon the final net profit figures of the corporations because the losses sustained by some corporations were not included in the adjustments to operating profit.

[6] Although the excess of income over interest cost per dollar of loan is shown in Table 22 to be more than 2 cents, that excess is due in part to the fact that 25 to 40 per cent of the loans are not rediscounted.

[7] Data for the banks were obtained from the following publications: FEDERAL RESERVE BOARD. EARNINGS AND EXPENSES OF MEMBER BANKS. Fed. Reserve Bul. 16: 411–413, 1930. POLE, J. W. REPORT OF THE COMPTROLLER OF THE CURRENCY. IN ANNUAL REPORT OF THE SECRETARY OF THE TREASURY ON THE STATE OF THE FINANCES * * * 1929. 1930.

Whereas the corporations paid out 53 per cent of their income for interest, the national banks in the same four States paid only 25 per cent and the banks in the Federal reserve system 33 per cent. Other operating expenses of the corporations took up 46 per cent of their income, those of one group of banks 45 per cent, and those of the other group 35 per cent. The small interest costs for banks, particularly the ones in the Southern States, reflect the fact that a large part of the loanable funds is obtained from noninterest-bearing demand deposits. As a matter of fact, a large part of the operating expenses of these banks is really part of the cost of getting loanable funds, for much of the labor cost is attributable to the deposit activities of the banks rather than to their direct-lending operations.

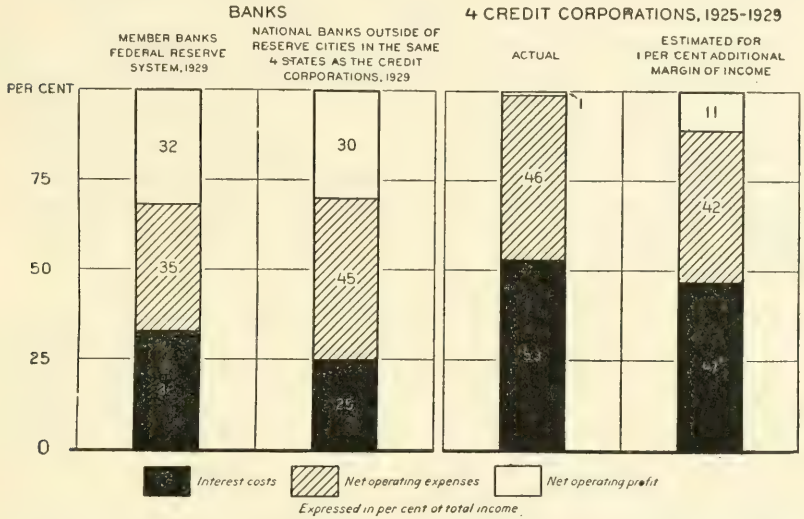

FIGURE 9.—OPERATING RESULTS OF BANKS AND AGRICULTURAL CREDIT CORPORATIONS

The operating results of four agricultural credit corporations are here compared with the operating results of national banks outside of reserve cities in the same four States and with those of the member banks of the Federal reserve system. The corporations earned a much smaller percentage of profit than either group of banks. The operating profits would have increased from 1 to 11 per cent if the corporations had earned an additional 1 per cent of interest on their loans. (Data for banks were obtained from the Federal Reserve Bulletin, July, 1930, and the Report of the Comptroller of Currency for 1929.)

Whatever the proper division may be between cost of getting funds to lend and other operating expenses of the banks, the fact stands out clearly that the sum of these two items represents to the banks only about 70 per cent of the income, whereas for the corporations it represents 99 per cent. Thus the corporations have an operating profit of 1 per cent, as compared with the 30 per cent for the banks.

The data in Table 23 on which Figure 9 is based are taken from the period prior to the date on which the corporations were permitted to increase their margin of earnings to 3 per cent. The last section of Table 23 and of Figure 9 indicate what the ratios would have been if an additional 1 per cent margin had been allowed. Net operating profit would have been 11 per cent of the income, assum-

ing that the increase of earnings would have had no effect on the volume of loans and the amount of expenses.

It is probable that the increase of operating spreads allowed the corporations will have a wholesome effect on this system of farm credit. The previous limitation of rates was an effort to protect the farmer, but to a certain extent the effort was self-defeating. Profits were so limited that private capital seeking profitable investment did not freely enter the business. As a consequence, borrowers have had to purchase the stock of the corporations themselves, and thus in a sense they have obtained loans only by cooperative endeavor. As a consequence of their investment in the corporations, on which they have usually suffered a loss of income and often of principal, their loans have cost them more than the regular interest charge.

If the additional profit allowed the corporations will attract private capital or if it will enable the borrower stockholders to obtain a return on their investment in the form of dividends on their stock, the increase in rates will be well worth while. Nor is it probable that the added margin of earnings permitted the corporations will make the costs to the borrower so high that this type of credit will not be wanted by the farmer. The average borrower of these corporations is interested in getting the advance of credit at any reasonable rate and is not borrowing to save the small excess of interest he would pay elsewhere.

SUPPLEMENTARY SOURCES OF INCOME

Because the income from interest was insufficient to meet the needs of these corporations several of them have found supplementary sources of revenue. One of the most successful attempts to add a source of revenue has been the practice on the part of a certain corporation of trading in its own stock, a discussion of which is included below. Another of the corporations attempted to add the selling of fertilizer as an additional line of activity, but the Federal intermediate credit bank refused to rediscount the paper originating in such sales on the ground that it was mercantile rather than agricultural paper. Some corporations sell fertilizer through a supply corporation, also a subsidiary of the cotton cooperative associations, but in such cases the profits do not go to the finance company itself but to one of the group of organizations of which it is a part.

INCOME-TAX PROVISIONS

The provision of the internal revenue act that exempts agricultural credit corporations affiliated with farmers' cooperative marketing associations from corporate-income taxation is seldom used. But it is interesting that such corporations are exempt if the dividend rate is limited. The following paragraph is taken from section 103 of the revenue act of 1928 from among the list of organizations specifically exempted.

(13) Corporations organized by an association exempt under the provisions of paragraph (12), or members thereof, for the purpose of financing the ordinary crop operations of such members or other producers, and operated in conjunction with such association. Exemption shall not be denied any such corporation because it has capital stock, if the dividend rate of such stock is fixed at not to exceed the legal rate of interest in the State of incorporation

or 8 per centum per annum, whichever is greater, on the value of the consideration for which the stock was issued, and if substantially all such stock (other than nonvoting preferred stock, the owners of which are not entitled or permitted to participate directly or indirectly, in the profits of the corporation, upon dissolution or otherwise, beyond the fixed dividends) is owned by such association, or members thereof; nor shall exemption be denied any such corporation because there is accumulated and maintained by it a reserve required by State law or a reasonable reserve for any necessary purpose.

At least three of the corporations studied have provisions limiting the amount of dividends that can be paid and thereby qualify for exemption from the Federal income tax.

DIVIDENDS, RESERVES, AND SURPLUSES

Little need be said regarding the dividend and reserve policies of these corporations. Only one corporation pays dividends and that is made possible largely because the cotton association pays the operating expenses. The dividend rate of this corporation is 8 per cent. The other corporations, with one exception, have not had sufficient earnings to pay dividends.

The size of reserves has generally been determined by the amount available and not by the need for them. One corporation made a special charge to borrowers of 1 per cent of the loan to be placed in a "reserve for losses," but this practice has been discontinued.

Accumulations of surplus have been small with the exception of those of the corporation mentioned above which turned its reserves for losses into the surplus account. In some cases large deficits have occurred. Table 24 shows the status of the net worth of five corporations as of the close of the 1929 lending season.

TABLE 24.—*Capital stock, surplus, and deficits for five corporations as of the close of the 1929 season*

Corporation	Capital stock	Reserves	Surplus or undivided profits	Deficit	Estimated losses not shown in balance sheet	Net worth
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
A	150,000		22,968			172,968
B	365,352	21,810	102,958		2,500	487,620
C	300,000	8,970	6,899		43,000	272,869
D	113,350			1,569	38,000	73,781
E	275,660			21,523	237,933	16,204
Total	1,204,362	30,780	132,825	23,092	321,433	1,023,442
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Percentage of capital stock	100.0	2.56	11.03	1.92	26.69	84.98

SPECIAL PROBLEMS OF CREDIT CORPORATIONS

OWNERSHIP OF STOCK BY BORROWERS

It has been practically impossible to sell the stock of these credit corporations to investors seeking profitable investments. Furthermore, few of the cooperative associations were able or inclined to buy all or even a large part of the stock themselves. As a consequence, borrowers in most of the corporations have been required to buy stock as a condition of getting the loan. The amount of stock that the borrower has been required to own has usually been 10 per

cent of the loan. This plan, adopted in the early years, was modeled somewhat after the national farm loan associations of the Federal land bank system. The ownership of the corporation by the borrowers makes the enterprise very much of the nature of a farmers' cooperative organization.

In the case of some of the corporations, the borrowers were permitted to purchase the stock out of the funds obtained from the loan. Thus those individuals were able to purchase the stock and pledge it as security without the advance of any funds of their own. The legal department of the Federal Intermediate Credit Bank of Columbia has ruled that such use of funds obtained from the bank is illegal under the terms of the law, on the grounds that it is not an agricultural purpose. This bank requires all borrowers to state in writing that none of the funds obtained from the bank will be used for the purchase of stock of an agricultural credit corporation.

It has sometimes been implied that collateral in the form of stock bought out of the proceeds of the loan is no better than none because the individual himself contributes nothing as security, the bank not only furnishing him money but also buying his stock. This implication is only partly true.

The matter may be considered from two points of view. From the standpoint of the security of the corporation on each particular loan such practice does not materially aid the corporation. It results in a debt approximately 10 per cent larger than would otherwise have occurred. If the farmer is unable to repay any more than the portion of the loan that went into the crop, then the additional security in the form of unpaid stock is ineffective as collateral. The corporation may resell it, but in that event, the corporation is no better off than if the borrower had never owned the stock. The only added advantage which the corporation has is that its claim against the borrower, after all other security has been exhausted, is larger than it would have been without the stock arrangement. This additional claim may be effective if a judgment is secured or may be well worth while if the following crop is successful.

From the standpoint of the security for the group as a whole, however, much can be said for the plan of requiring the borrowers to take stock even though they pay for it out of the loans. Although some individual borrowers may not be able in the fall to pay for their stock in addition to repaying the loan on their crops, many of them will. The amount thus paid in will provide the corporation with a capital fund to meet the losses on those accounts that can not be collected. Thus for the group as a whole, stock purchased out of the proceeds of the loans serves fairly well for security although not so well as stock purchased for cash.

One of the most objectionable features of the ownership of stock by the borrowers is that the situation is often misunderstood. The borrower, a farmer who has very little acquaintance with financial matters, considers that the stock he has been required to buy is of the same nature as the note he has given to the corporation. He often feels that if he repays his note the corporation should refund him the value of the stock. In many cases where it has been difficult to collect the loan, the borrower has contended that if the corporation would repay him the value of his stock he would pay to the corpora-

tion the balance on his loan. He often feels it an injustice that he should be required to pay his note in full and yet not get back the money he contributed to the formation of the corporation. Such a misunderstanding causes trouble and gives the corporations and the Federal intermediate credit system a bad reputation. In fact, some persons have felt that this is the principal reason why the practice should be abandoned.

The enforced purchase of stock by borrowers is made more unsatisfactory by the frequent occurrence of depreciation in the value of the stock. The value is largely dependent upon four factors: (1) Dividends received, (2) services received, (3) the market for the stock, and (4) its ultimate liquidating value. Dividends have been paid on the stock of only one of the corporations in this study. Consequently, return on investment in the form of dividends does not contribute toward supporting the value except in that one case. The service received by many individuals is sufficient to justify the ownership of the stock, and if the borrower is satisfactorily obtaining a loan every year he has little desire to get rid of his stock. In such cases, the stock continues to have a value for the owner. But in the case of persons who have discontinued borrowing the situation is entirely different. They are able to benefit from the stock neither through dividends nor through service. Moreover, there is practically no market for the stock. Some corporations act as resale agents, selling the stock to new borrowers, but most of them are unable either legally or financially to repurchase the stock for holding in the treasury. Consequently, there is a ready market for the stock only while the corporation is expanding and gaining more borrowers than it is losing.

One of the credit corporations makes trading in its own stock an important supplementary source of income. Borrowers are required to buy stock in order to obtain a loan, and stock purchased from sources other than the corporation is not acceptable. Partly for this reason and partly because the stock does not pay dividends, there is no buyer for the stock except the corporation itself, and, being the sole party interested in buying the stock, the corporation can set its own price.

The price it offers depends on the borrower's record. If his account has been hard to collect and has thus involved extra expense, the corporation will not offer full value for the stock. If on the other hand the individual's account has been a good one, and he does not need to borrow further, the corporation will buy his stock for the full value. But since most of those who do not borrow again have had unsatisfactory records, the price is usually much below par value. In fact, the average price paid has been slightly less than 50 per cent of par value. The owner sells at that price because it is his only opportunity to sell. The corporation then resells this stock at par value to new borrowers and makes a substantial profit. At the time the study of that corporation was made, the profits from this source had been about sufficient to absorb all of the losses on loans.

In addition to providing supplementary income, this practice has brought about some very satisfactory results. The capital of the

corporation, which would otherwise have been impaired through losses on loans, is kept intact and the balance sheet shows a surplus rather than a deficit. Had the corporation sold new stock to new borrowers instead of treasury stock the corporation would have acquired more funds, it is true, but the capital would have been impaired from losses on loans. With the capital impaired and a large amount of nondividend-paying stock in the hands of previous borrowers with no buyer to take it, the market value of the stock would have dropped very near to zero, and would probably have reflected on the credit of the company. Under the present plan the corporation's stock has a probable liquidating value equal to par and a market value equal to par for those borrowers whose accounts are satisfactory.

It has been contended that the above plan is merely another means of increasing the charge for the loan. That is true not only of this plan but of practically all plans that require the borrower to buy stock. Borrowers in most cases must purchase stock if the credit corporations are to be organized at all, because others will not invest in a business that can not operate at a profit. The cost of the loan to the borrower thus includes more than the interest paid. But the plan outlined is one by which the extra charge is largely placed upon the borrower who contributes to the high cost of doing business by failing to pay his loan promptly. In consideration of the extra service required on his loan and the extraordinary risk involved in his case, the cost to him is probably not excessive. If the loans were all as difficult to collect and as hazardous as his the corporation would probably fail and the stock would be worth nothing.

The desirability of this plan depends largely on the character of its administration. Improperly used it can work a serious injustice. Properly administered it can be equitable and still provide a substantial supplementary revenue.

LOCAL LOAN GROUPS

Several of the corporations have experimented with local loan groups. These are unincorporated organizations of borrowers, usually confined to one locality or county, which operate as local contacts for State corporations. Borrowers are expected to own stock of the State corporation and all members of the group mutually pledge the stock they own for loans of all others in the group. In other words, the stock of all members of the group is pooled as a guarantee of any and every loan within that group.[8]

The advantages of this plan are (1) that the mutual guarantee strengthens the loans, (2) many of the weaker credit risks are eliminated, for members of the groups will not want to admit them, and (3) the corporation is able to dispense with some of the field work which otherwise would be necessary, for the officers of the local groups will do part of that work. Moreover the cost of field work will be kept at a minimum, for loans will be concentrated in certain sections.

There are several objections to this plan. In the first place, the State corporation can not grant to the local groups the discretion which they often want in making the loans, for the guarantee (stock

[8] See appendix for a sample copy of such an agreement.

equal to 10 per cent of the total loans) is too small to warrant the grant of such wide powers. In the second place, farmers are often too independent to want to combine with others and guarantee the payment of their notes even to a limited extent.

Whereas cooperative credit societies are common among European farmers, the American farmer is an individualist. But necessity may drive him to cooperate. It is of interest that four corporations in the cotton States adopted this plan in 1931, although these four are not all affiliates of the cotton-marketing associations. If prosperity returns to the cotton farmer, it is possible that he will become dissatisfied with absorbing the losses of others and will break away from the local groups. Unfortunately he does not realize that when he deals independently with a bank or credit merchant he pays for the losses of the others in the form of interest or other charges.

A modification of this plan of mutual guarantee by a local group is found in one of the corporations. Some of its loans are arranged for it through local banks and are partially or in full guaranteed by them. Instead of the borrowers buying stock, the bank itself may do so on its own account. By pledging all of this stock as security for any and every loan placed through it, a special reduction in the cost of the loan to the borrower is obtained.

EXTENT OF AFFILIATION WITH COOPERATIVE MARKETING ASSOCIATION

Just how closely the cooperative marketing association and the credit corporation should be affiliated is an unsettled question. The question whether a cooperative marketing association should purchase the stock of its affiliated credit corporation might be considered first. Various practices are found among the cotton associations. The marketing association in Texas owned all the stock of the finance corporation. In some of the other States, the cooperative has owned a much smaller amount, whereas the borrowers own the majority. In other cases the cooperative owns none of the stock.

The source of funds used to purchase this stock is ordinarily the reserves of the cooperative, although in 1930 two of the associations borrowed the funds from the Federal Farm Board. It is doubtful whether an association should jeopardize the reserves belonging to its members or its own credit by investing money in the stock of a finance corporation, particularly when such organizations in many cases have proved unprofitable. Moreover, there is a serious question of equity and justice among the members involved. As a rule only a small portion of the members obtain loans, and it is questionable whether the funds belonging to all of the members should be invested and jeopardized for the benefit of only a few. Of course, if the added volume of business acquired through the use of the finance corporation results in reducing the unit costs of operating to a considerable amount, the investment might be profitable for non-borrowers as well as borrowers. But it is probable that such reduction in cost has not occurred from the organization of most of the credit corporations affiliated with the cotton marketing associations.

Several of the cooperative associations have paid the salaries of the corporations' employees, and some have paid all the expenses of their finance corporation. These expenses may be divided into two classes, (1) direct expenses of the corporation and (2) joint

expenses that the cooperative would have anyway such as salaries of their field men, who may give some time to the business of the corporation. There seems to be little question but that the cooperative could well pay the joint expenses of both the organizations since it would have to pay practically that amount for its own purposes. Whether the cooperative should pay the direct expenses of the corporation will depend upon whether the benefits to it are equivalent to the outlay.

Another important question in the matter of affiliation is whether both organizations should be operated under the same management. There are several advantages of close affiliation. The work of the two organizations is closely coordinated for mutual benefits, and there is the advantage of economy in operation. On the other hand, when such an arrangement exists, the members seldom distinguish between the two organizations. Ill feeling caused by the refusal to grant loans or vigorous collection methods is then directed not only against the finance corporation but against the marketing association as well. In fact, such an arrangement may result in the loss of a considerable number of members. Another objection to placing the finance corporation under the same management as the cooperative marketing association is that the executives of that association may jeopardize the interests of the stockholders of the finance corporation in order to increase the membership of their association.

One of the largest expenses of operating both a cooperative and a credit corporation is the cost of maintaining a field force and of paying its traveling expenses. If the field men of the cotton association could satisfactorily take care of the credit work a real savings would result. But the use of the field staff of the association by the corporation has often proved unsatisfactory. Field men are usually salesmen and not credit men. They are generally anxious to make loans in order to get new members and are seldom able, or willing, to judge carefully the applications for loans. During the picking season, when they should be busy signing up new members, their time, if they represent both organizations, is used in checking up on borrowers to see that loans are paid. Thus valuable time is lost from their principal work. Moreover, while enforcing the collection of loans, they are likely to make enemies rather than friends.

It has been thought by some that the best plan is for the corporation to have a small force of field men of its own, and to have the association's field men serve only in an advisory capacity, and as a source of information relative to the credit standing of individuals and to the amount of cotton they have to deliver.

EXCESSIVE HAZARDS OF THE LOANS

One of the chief problems of the agricultural credit corporations that finance cotton production is the hazardous character of the loans. The single-crop system causes the creditor to take an excessive amount of risk. The success of the crop is dependent on the weather conditions, and heavy rains, hail, drought, or floods may practically destroy the whole crop. Furthermore, the crop is subject to boll-weevil and other insect infestation which may also completely destroy it. Last of all the repayment of the loan depends to a large

extent on the price obtained for the crop. In past years when cotton prices have been high, it has often been profitable to plant all the land in cotton and to buy all of the feed and food necessary. This practice has been carried over into years when cotton prices were low and has contributed greatly to the hazards of lending.

Another factor contributing to the hazards of lending to the cotton farmer has been the excessive use of credit. This is largely a result of the single-crop system whereby the farmer devotes his entire time to the production of a cash crop instead of providing a living for himself on the farm. As a consequence it is necessary to buy a large part or all of the provisions, most of which have to be obtained on credit. Periods of high prices for cotton during the World War, and during some years since the war, have made it relatively easy to repay large loans out of the proceeds of the crop, but with low prices of cotton the advances to which farmers were accustomed have proved excessive.

One of the most important causes of the credit difficulties of farmers is the fact that they have accumulated little property. Many farms, after a hundred or more years of cultivation, show nothing in the form of accumulated wealth except a few dilapidated dwellings, a little machinery, and several poorly fed animals. The accumulation of wealth often amounts to far less than the depletion in the fertility of the soil. Although some farmers have made substantial outside investments, many of them have little or nothing more than their farm properties, which often are heavily mortgaged. As these represent most of the accumulated wealth, borrowing must be based largely on wealth yet to be created and loans must be secured primarily by a crop not yet grown; the creditor's participation in the growing of a crop on this basis is but little more than a partnership interest.

If the farmer has accumulated some wealth in the form of livestock, equipment, and land free from mortgage, or investments, he is able to borrow much more easily and at a lower cost. Such a loan is less hazardous to the creditor because it can be secured by existing property and can be liquidated regardless of whether the crop is a success. Moreover, when a loan is based upon sound security, less consideration need be given by the creditor to the borrower's plan of operation. Little or no need will arise for supervising the operations of the borrower or for watching to see that he applies the income from the crop to the debt. As a consequence, the cost of making and servicing the loan will be less, and under competitive conditions, this reduction of cost to the creditor should be reflected in a reduction of charges to the borrower.

It is possible that, should agricultural credit corporations owned by borrowers prove to be successful and stable institutions, they may become a satisfactory place for permanent and extensive investments by farmers. If, instead of requiring the borrower to take stock equal to 10 per cent of his loan the first year only they should require the borrower to take stock equal to 5 or 10 per cent of his loan every year, the farmer would soon acquire a substantial investment. As his investment in the corporation increases, it should become increasingly easier every year for him to obtain the credit needed for farming operations because the margin of safety to the corporation would become greater every year. Ultimately, if he owns stock equal to the

amount of credit he needs to grow his crops he should be able to obtain a loan by merely pledging his stock and giving a mortgage on his crop. Little if any investigation would be needed.

This plan would not only make it easier for the grower to obtain his loan, but it would tend to reduce the costs of the loan to him for the lower cost of operation, and the smaller losses of the corporations should be reflected back to the stockholder. The corporation would gradually accumulate a capital sufficient to make a large portion of its loans out of its own funds. With plenty of capital and plenty of loans to offer as collateral, it could more easily borrow what funds it needed from the Federal intermediate credit bank, and in this way the operation of the corporation would be facilitated.

This plan could be recommended only in case an agricultural credit corporation proved to be a sound, stable institution in which there was little risk of impairment of capital. It would be unwise, at present, to recommend that farmers invest a large part of their savings in these institutions. It is hoped that with the recent increase of 1 per cent in the margin of earnings allowed the corporations, these organizations will become stronger and more substantial. In that event they may be recommended to farmers as a satisfactory place for the investment of accumulated savings.

AN APPRAISAL OF THE CORPORATIONS

An appraisal of the corporations included in this study should include a consideration of three factors: (1) Importance of agricultural credit corporations as a source of farm credit, (2) desirability of state-wide operations, and (3) affiliation with cooperative marketing associations.

AGRICULTURAL CREDIT CORPORATIONS AS A SOURCE OF CREDIT FOR FARMERS

As a source of credit for cotton farmers, the agricultural credit corporations, from some standpoints, compare very favorably with other agencies. If they have the necessary capital, there is practically no limit to the amount of loanable funds which is available through them on good paper. The Federal intermediate credit banks tap an immense reservoir of credit which would not be seriously affected by failure of the cotton crop in one particular State or area.

The case is different for most local lending agencies. Both the local banks and the local credit merchants are adversely affected by poor crops in their territory because they depend to a large extent on local funds for lending purposes. Moreover, in the same years that local funds are at a low level because of a poor crop or poor prices, the credit of these local agencies with large city banks and merchandise companies is restricted. Thus failure of a crop or a poor price results in a scarcity of loanable funds and a restriction on loans the following year not only for farmers whose credit is impaired but for those whose credit is sound. On the other hand, if an agricultural credit corporation can keep its capital from being seriously impaired in a bad year or can increase the capital readily by selling more stock, it has an almost unlimited source of credit available for good paper in the following year.

It has often been contended that agricultural credit corporations are better suited to handle crop-production credit than are commercial banks; that they do not have demand liabilities (deposits) and

consequently are able, without incurring as great risks, to loan on paper of the term of eight or nine months needed for the crop. Certain studies have shown, however, that banks in some areas can satisfactorily carry paper with a term of a year or more in their portfolios.[9] In an area with highly seasonal credit needs, such as the Cotton Belt, the banks probably feel more strain at the peak of the season than do the agricultural credit corporations. At the same time that the loans of the banks are approaching a peak as a result of seasonal requirements for the farming operations of borrowers the depositors are withdrawing their funds for use in their own farming operations. But again, it is difficult to generalize, for many banks in the cotton area are able to borrow from the city correspondents or to rediscount paper with them at the peak of the lending season.

Agricultural credit corporations are probably better prepared to extend credit to farmers than are most merchants. Analyzing credit risks is the principal work of the personnel of the credit corporations, whereas it is often a secondary and incidental task for the merchants. In fact, analysis of the farmers' financial statements and other data are the exceptions and not the rule with the merchants. Their margins are wide, and thus they are not compelled to study so minutely the possibilities of loss. Wide margins for merchants have tended to promote a grouping of risks, whereas narrow margins for the credit corporations have promoted a classification of risks. Furthermore, agricultural credit corporations, through the Federal intermediate credit system, are able to obtain their funds at a lower cost than are merchants, and as a result of that and other factors the cost of credit to farmers through the corporations has been smaller.

The credit corporations included in this study, except in one or two instances, have not furnished a sufficient volume of credit to affect materially the general market rate of interest or other costs of money in their areas. In most cases the operations have covered large areas and have not been concentrated sufficiently to afford real competition for other lending agencies. It is probable, however, that some members of the marketing associations have been able at times to obtain better terms or better rates on loans by threatening to borrow from the credit corporation instead of local credit agencies.

As has been pointed out, one of the principal defects of this system of agricultural credit is the amount of red tape involved in getting loans. Whereas the farmer who borrows from a local bank is often able to obtain a loan immediately upon asking for it, and merely by signing his name, the borrower from the corporation has to prepare a long and detailed application and financial statement, take an oath as to its accuracy before a notary public or other officer, have the records searched for prior liens, sign a half dozen or more papers, record the mortgages, and then wait two or three weeks while the papers take seven or eight trips through the mails. If, on account of his lack of acquaintance with these legal papers which he has occasion to study only once a year, the borrower makes a slight error, the papers are returned to him, causing a further delay of

[9] GARLOCK, F. L. LONG TERM LOANS OF IOWA BANKS. Iowa Agr. Expt. Sta. Research Bul. 129, p. 254–300, illus. 1930.

several days or a week. Meanwhile the season advances while he waits for the credit to buy his fertilizer.

Some improvement has resulted from the change of the law in 1930 which permits the Federal intermediate credit banks to lend directly to the agricultural credit corporations on the security of farmers' notes as an alternative to rediscounting the notes themselves. Correction of minor errors in the papers creates less delay in the advancing of credit by the banks for other collateral can be substituted during the interim period. This provision adds some of the much-needed flexibility to the system.

Some persons have felt that the agricultural credit corporations have not served farmers as they should because of the high standard for loans set by the Federal intermediate credit banks. It has been said that the only persons who could get loans from the intermediate credit banks through the corporations were those who could get loans from any local bank. The implication is that the intermediate credit banks were formed to lend on a poorer class of paper than commercial banks ordinarily will accept. There is nothing in the act which created the Federal intermediate credit banks that indicates this.

The banks were created to fill a need for credit of a term shorter than the usual mortgage loans on land and longer than the customary commercial bank loans. Maximum and minimum terms of three years and six months, respectively, were set. Experience has failed to demonstrate, however, that loans of maximum term were satisfactory or needed; consequently the loans of the system have been largely from six months to one year with an extension often granted in the case of livestock loans if the security justified it. In 1930, the lower limit of six months was removed. Modeled somewhat after the War Finance Corporation, the system was intended also to supplement commercial banks wherever necessary. This it is doing at present in some regions where banking resources are insufficient to meet the needs of agriculture; in regions where banking resources are ample this type of farm credit has not been used to a great extent. The act, however, contains no implications that the system was set up to handle loans that commercial banks could not carry on account of the risk involved.

Whether the local banks or the agricultural credit corporations get the better paper is a moot question. Obviously, no one answer could cover the situation for all local banks and all corporations. In a region where local bank facilities are ample and interest rates are reasonable the tendency would probably be for the corporations and Federal intermediate credit banks to get the poorer paper. Prosperous farmers maintain business relations with their banks, and if they can get loans at reasonable rates from the banks they will not be inclined to borrow from the credit corporations through which it is much less convenient to obtain loans. Moreover, bankers have a personal acquaintance with their customers, and they will attempt to keep for the bank those loans that are the least hazardous even if they have to make some concessions in interest charges. Those whom the banks will not accommodate will seek loans from the credit corporation. On the other hand prosperous economical farmers will often seek loans through credit corporations if the costs are lower than from the banks. Again in some cases the local banks can not make loans large enough to accommodate large operators.

Some maintain that the agricultural credit corporations get the "best risks" because the Federal intermediate credit banks set up rigid requirements for loans and only the very best paper is taken regardless of the needs of the farmers. The local banks must take the remainder. It is logical to conclude, however, that neither type of institution has a monopoly on the best paper to the exclusion of the other.

STATE-WIDE OPERATIONS

Both advantages and disadvantages are to be found in State-wide operation of agricultural credit corporations. The corporation operating over a whole State is able to obtain a wider diversification of risks than one whose territory is more restricted. Rain, hail, flood, droughts, and insect infestation are not likely to affect so large a portion of the loans of a corporation operating over a whole State as they would of a corporation operating in the retail trade territory of a single city or town. In addition, the State corporation is able to obtain a large enough volume of business to hire full-time employees and capable management.

On the other hand there are counterbalancing advantages for the local agencies. By being personally acquainted with the borrower and having a knowledge of his farm, officers of local agencies are better able to judge the probable yield of the crops, the value of the security, the ability of the farmer, and his personality and character. Moreover, they are in a position to keep a constant watch on the progress of the crop. The agricultural credit corporation operating over a whole State finds it much more difficult to obtain this information. It must depend on the statements of local persons for a knowledge of the personal characteristics of the borrower and sometimes for a knowledge of his farm and operations; such information is not always reliable because local persons may be anxious to have the loan made. Then, too, the corporation must send its field men long distances to visit the farm, possibly to appraise the security before making the loan, to watch the progress of the crop during the summer, and to prevent illegal sale of the cotton during the picking season. This is expensive and not so satisfactory as local supervision, although it is sometimes claimed that the field men of the corporation devoting their full time to the work often know the condition of loans and security better than do the officials of many of the local lending agencies.

Another advantage of the local lending agency is that an unreliable borrower is more inclined to pay local debts than debts to an outside corporation for he does not wish to lose his credit in the community. In fact it is sometimes hard for an outside corporation to secure judgment against a man in his own community before a jury of his neighbors.

The plan of having local unincorporated groups pass upon the paper submitted and guarantee that paper to the extent of their stock in the State credit corporation is a worthy attempt to obtain the volume of business and diversification of risks which go with a State corporation while at the same time obtaining many of the benefits of local organizations.

An experiment not yet tried is that of the cooperative marketing association having a number of affiliated local credit corporations

scattered throughout the State. There is serious doubt whether the volume of production credit needed for members of the cooperative would be sufficient in local areas to support the activities of such corporations. The plan might be possible, however, if these corporations did not confine their activities exclusively to members of the marketing association.

RELATIONS WITH COOPERATIVE MARKETING ASSOCIATIONS

In studying the relationships between the credit corporations and the cotton associations one should have in mind the conditions which led to the organization of the subsidiary or affiliated finance corporations, changes that have occurred in the conditions since their organization, and subsequently revised concepts of the function of the subsidiaries. It should be recalled that association members were thought to be hampered in the delivery of their cotton to the cooperatives by the control exercised over them by their creditors. The corporations were set up largely to remedy this situation although it was also expected that they would attract new members to the marketing associations and would render the members a much-needed financial service.

The situation has changed materially during recent years. Loans made to the cooperative associations by the Federal Farm Board in 1929 and 1930, enabling them to advance the farmer approximately 90 per cent of the market value of the cotton at the time of delivery, have made it possible for more farmers to liquidate their indebtedness on the crop out of the association's advance than could have done so in previous years. Since borrowers could pay their debts out of the association's advance the creditors have had little grounds for objection to marketing through the cooperative. Moreover, if the value of the cotton produced has been insufficient to liquidate the debt, the creditors have often been willing to take 90 per cent of current market value in part liquidation with the chances of recovering more than the extra 10 per cent if prices advanced while the cotton was held by the cooperative association.

Another factor that has changed the situation in late years has been the scarcity of loanable funds of local credit agencies. In many cases local agencies have been unable to provide the amount of credit needed in the community and have been glad to have some of the farmers obtain funds through the Federal intermediate credit system. This condition has tended to break down the opposition to the cooperative program.

At the same time the shortage of credit supplied by other agencies has made the granting of production credit by the associations or their subsidiaries a more needed service for members. Whereas, in the past, the chief purpose of the corporations was to enable members to make deliveries of cotton by throwing off the control of other creditors, the chief purpose to-day is to render a needed financial service to members.

The extent to which the agricultural credit corporations have aided the marketing associations to obtain cotton is unknown and can not be accurately measured. Figure 10 shows for comparative purposes the trend of deliveries of 12 cooperative cotton marketing associations and the trend of loans of their 11 affiliated agricultural

credit corporations. In order to eliminate the fluctuations in trend due to the size of the crop the deliveries have been adjusted for yearly variations in production by States. A comparison of the trend of deliveries (adjusted) with the volume of loans indicates very little relation. In fact, the trends are in opposite directions about as often as they are in the same direction. Three similar analyses of individual associations and their credit corporations show results comparable to the results of the above comparison for 12 associations combined. It would appear therefore that other factors were of far greater importance than the amount of production credit extended in determining the volume of deliveries.

The termination of the original 5-year contracts is easily discernible in the deliveries for 1926, 1927, and 1928, and the influence of the Federal Farm Board is to be noticed in their upward trend

FIGURE 10.—DELIVERIES OF COTTON TO 12 COOPERATIVE MARKETING ASSOCIATIONS AND THE VOLUME OF NEW PRODUCTION LOANS MADE YEARLY BY THEIR 11 AFFILIATED CREDIT CORPORATIONS

The trends of the loan curve and the delivery curves show little relationship between the two. Moreover, a comparison of the deliveries and the estimated number of bales financed indicates that production credit is a minor factor in determining the amount of cotton delivered.

in 1929 and 1930. The estimated baleage financed by the corporations represents only a relatively small portion of the total cotton handled and supports the conclusion stated above that the financing of production is only a minor factor in obtaining deliveries.

Furthermore, it must not be assumed that all of the cotton obtained from borrowers would not have been delivered to the associations unless it had been financed. Many borrowers were members of the marketing associations in years before they obtained loans of the credit corporations, and undoubtedly many would market their cotton through the associations regardless of whether they obtained credit from the affiliated corporation.

On the other hand it is doubtful whether a comparison of deliveries and loans reflects the full influence of subsidiary or affiliated credit corporations in obtaining cotton for the associations. The very existence of a credit corporation whose services are available to members is a strong bargaining point for the member in his rela-

tions with his creditors. It is entirely possible that the deliveries obtained by making at least some of the members more free from the dictates of their creditors have been larger than the amount of cotton financed.

The management of one of the cooperative marketing associations feels that the finance corporation has an indirect value for the marketing association in that the delivery of mortgaged cotton starts the flow of cotton to the cooperative early in the fall. The shipment of that cotton provides the farmers of the State with concrete evidence that others think it worth while to market their cotton through the cooperative association.

But the activities of the finance corporations have resulted in losses, as well as gains, in membership. Creditors are popular when loans are being made but very unpopular at collection time. Rigid measures necessary to enforce collection result in a loss of some of the good will gained by granting the loan. This is especially true in years when there are poor crops. Discontent is caused by refusal to grant loans that are not sound. It has often been necessary to refuse many more loans than could be granted, and such a situation requires delicate treatment to prevent the loss of members.

The activities of the credit corporations have often been hampered by the policies of the marketing associations. These finance corporations have not been free to go out and get the type of business they have wanted and needed. They have been required to wait for business to come to them and have been restrained from soliciting it because the competition with local credit agencies thus created might make enemies for the cotton associations among the bankers and business men. The credit corporations have been permitted to make loans only to association members and have been unable to refuse a loan to any member because of it being too small to be profitable. As a consequence of these handicaps the size of loans has been small, the volume has been restricted, and the loans have been scattered over a wide area. These conditions have resulted in restricted incomes and excessive expenses, in some cases bringing about an impairment of the capital.

CONCLUSIONS

Conclusions regarding the corporations included in this study and any suggestions for future policy will depend on the point of view taken as to their fundamental purpose. Are these corporations to be judged on the basis of their own showing as agricultural credit institutions or as a part of the cooperative marketing movement? Furthermore, to render the greatest service to all concerned should they continue to be affiliated with the marketing associations?

As financial institutions purely, their record, with few exceptions, has been disappointing. They have financed in all but one case only a very small portion of the farmers in their area—almost a negligible portion—although the business which they have done in those communities where banks have failed was undoubtedly a real help. In 1930, the combined volume of business was the highest of any year, but that was largely due to the rapid expansion of one of the most successful corporations, its business representing more than 60 per cent of the total. Many of those corporations that contributed to the large total volume of business in 1926 were out of business

or in liquidation by 1930. Half of the corporations that have been organized have failed or have voluntarily gone out of business, and in 1931 only a few of them were agressively going forward. In passing judgment on them, however, it should be kept in mind that farm credit agencies of other kinds have failed in large numbers during the same years.

There have been a number of causes of failure, chief among which have been: (1) Large losses on loans due to low prices of cotton, to the single-crop type of farming, resulting in excessive borrowing and excessive hazards, and to the lack of sufficient reserves of the borrowers, resulting in the security being often limited to a crop lien; (2) limitations of earnings, due both to legal limitations on interest charges and to the seasonal character of the business, so that the accumulation of reserves sufficient to meet the losses has been very difficult; (3) relatively high costs of operation, due to the small size and scattered location of the loans; (4) inefficient management in some instances; and (5) the practice in the early years of granting doubtful loans in order to induce farmers to join the marketing associations. The immediate cause for discontinuance of operations by three of the corporations has been the inability to get credit from the Federal intermediate credit banks as a result of the impairment of capital from an accumulation of uncollectible or frozen loans. Three others discontinued operations after a small experiment of a year or two had disclosed the difficulties of furnishing production credit. Two of the corporations went out of business because the parent organization failed.

In addition to making an unimpressive showing as financing institutions, the corporations usually have failed to give substantial aid to the marketing associations. Estimates of the number of bales of cotton financed by all corporations have at no time placed them in excess of one-fourth of the total deliveries, and in the case of some corporations the portion of deliveries obtained by financing the crop has been negligible. Moreover, the volume of financing does not appear to have borne a close relationship to the volume of cotton delivered. (Fig. 10.) Nevertheless, some of the corporations have cost the parent associations substantial sums in the way of expenses of operation, the sacrifice of income on investments in their capital stock, and losses in the value of that stock.

The case for agricultural credit corporations rests to-day not upon the needs of the cotton cooperative marketing associations for a financial subsidiary but upon the needs of farmers for credit. Although a number of the corporations have failed and most of them have proven relatively ineffective as a means of building up the marketing associations, it can not be gainsaid that they have rendered a real service to the members who have obtained loans. It is to be regretted that the service has been limited to such a small proportion of the farmers who needed it and that the cost to the cooperative or the other stockholders has been so high.

The adoption of certain new policies might help to remedy the situation, although financing the production of cotton at present prices is an extremely difficult task. Despite the fact that several corporations are operating successfully while financing only association members, it is believed that many of the corporations would be strengthened and a greater service would be rendered to the

farmers of the States if their services were not confined to members of the marketing associations, if they were not obligated to serve all members of the associations alike, and if they were free to solicit loans. Their services would thus be available to five or six times as many farmers. Having a larger group to serve and being free to make loans to nonmembers, they could obtain a larger volume of business and thus operate at lower unit costs. They could also concentrate their activities in certain areas through making loans in those areas and refusing scattered applicants in others. By soliciting large, safe loans and refusing the extremely small, unprofitable ones they could operate much more successfully.

Were this extra freedom of action to result in stronger credit corporations, the cotton associations and their members would benefit by extending the services to nonmembers. The marketing associations, it is true, would lose the business of those borrowers who market their cotton through the associations merely to get the financing service, but, on the other hand, they would not have to contribute so much to the support of the corporations. The membership of the associations might not be willing to extend the benefits of their organization to nonmembers; in such event the only way to obtain the freedom of action desired would be to have separate and distinct credit institutions.

The organization of independent corporations raises certain other problems. Who will promote them? Who will finance them? Even if the borrowers are required to buy stock it can not be expected that the cooperative marketing associations will provide the original capital as they did for many of their subsidiaries. Would it be possible and desirable to obtain funds from bankers and business men and, if so, would these men control the corporation or would it be primarily a farmers' cooperative enterprise controlled by farmers?

It is entirely possible that in certain cases cooperative financing may render as great a service to farmers as cooperative marketing. The marketing associations could well lend a helping hand or even take the initiative in sponsoring the movement for farmers. With their mailing lists, their field staffs, and their wide contacts, they are in an excellent position to aid groups of farmers who would like to have a cooperative credit institution for financing the production of their crops. The two farmers' organizations could aid each other. The finance cooperative would obtain the advantage of collecting its loans through the marketing association. The marketing association by sponsoring such a corporation would be rendering a service to its members who needed a new source of financing. Under this plan no part of the cost of financing crops of others would fall upon those members of the marketing association who did not care for or could not qualify for loans from the corporation.

APPENDIX

CONTRACT BETWEEN GROWERS AGRICULTURAL CREDIT CORPORATION AND MEMBERS OF LOCAL GROUPS

THIS AGREEMENT, made on this ___ day of _____, 193 _, by and between those persons who are or do become members of that certain organization known as _____ Credit Group, parties of the first part, and Growers Agricultural Credit Corporation, a corporation chartered and existing under and by virtue of the laws of the State of North Carolina, with its principal office in Wake County, North Carolina, party of the second part, WITNESSETH:

WHEREAS the party of the second part is engaged in the business of extending agricultural credits; Whereas the parties of the first part contemplate applying to the party of the second part to obtain loans for agricultural purposes; and WHEREAS the parties of the first part desire to secure in a measure the party of the second part against losses resulting from any loans made to member of the aforesaid Credit Group.

NOW, THEREFORE, for and in consideration of the premises, and for the sum of $1.00, paid to the parties of the first part by the party of the second part, the receipt whereof is hereby acknowledged, the parties of the first part make and enter into the following agreements and promises:

1. That the parties of the first part will exercise due diligence in submitting to the party of the second part applications for loans only in behalf of persons worthy of the credit requested, in seeing that all applications, financial statements, and other loan papers submitted by them are correctly and fully filled out and in helping to collect on or before date of maturity all loans made to the parties of the first part.

2. That _____ has been selected to serve as Chairman of this Credit Group; _____ has been selected to serve as Secretary of this Credit Group; the following persons have been selected to serve as Executive and Loan Committee for this Credit Group; said Committee to consist of not less than three persons and not more than five persons, it being permissible for either Chairman or Secretary, or both, to be members of said Committee:

_____, _____,

_____, _____

_____.

3. The Chairman and Secretary of said Credit Group shall serve for a period of one year and until their successors are selected and qualified; in case of vacancy the Executive and Loan Committee shall have authority to select a new Chairman or new Secretary; the members of the Executive and Loan Committee shall serve for a period of one year and until their successors are selected and qualified; in case of vacancies, the remaining members of said Committee shall have authority to fill same; the Chairman and Secretary acting jointly can call a meeting of the members of the aforesaid Credit Group, either on some date in January of each year, or at any other time that they might deem said meeting desirable or at any other time that said meeting might be requested by written petition of one-half of the members of said Credit Group.

4. That all applications for loans for members of said Credit Group must be approved in writing by at least three members of the Executive and Loan Committee; all notes submitted for members of said Credit Group shall bear some signature, stamp, or other appropriate writing, to be made by the Secretary, to identify said notes as coming from the aforesaid Credit Group; and it is distinctly understood that in submitting and handling applications for loans, in handling proceeds of notes and in all other matters relating to loans, the Chairman, Secretary, and Executive and Loan Committee will be acting as the agent of each individual borrower and not in any sense or in any respect as the agent of the party of the second part.

5. That the signing of this Agreement by the aforesaid persons designated as Chairman and Secretary shall bind and make parties to this contract all members of the aforesaid Credit Group and all persons who at any time might obtain loans through this Credit Group; the procurement of a loan through this Credit Group by any person shall make that person a member of this Credit Group and shall constitute on the part of said person approval and ratification of the provisions of this Agreement; and, though many members of said Credit Group might sign this instrument as evidence of their having actual notice of the provisions hereof and as personal commitment thereto, failure on the part of any person to sign this instrument shall not relieve said person of any obligation hereunder provided said person applies for and obtains a loan through this Credit Group.

6. That the capital stock in the party of the second part owned by members of the aforesaid Credit Group is hereby assigned, pledged and transferred to the party of the second part, its assigns and successors, as collateral security for the payment of all notes signed by members of said Credit Group. This

assignment and pledge of capital stock includes all stock that has already been purchased and all stock that might in the future be purchased by members of said Credit Group. In case of any certificates of stock that have already been issued or that might in the future be issued to members of said Credit Group, they appoint and constitute the Secretary of the party of the second part as true and lawful attorney in fact to execute the proper assignment of said stock certificates, hereby giving to said party full power and authority to assign and transfer said stock certificates, in accordance with the foregoing provisions, hereby ratifying and confirming all acts and deeds done by the said attorney in fact just as if same had been done by each of the parties of the first part personally and acting for himself.

7. If on the 15th day of December of each year, the party of the second part holds any uncollected notes signed by members of the aforesaid Credit Group, or if the party of the second part has suffered any losses or incurred any expense for attorney's fees or other efforts to collect the notes of any of the members of said Credit Group, said party of the second part may, at any time after said date, sell the aforesaid stock of all the members of said Credit Group, proceeds of said sale to be applied towards the payment of said uncollected notes and/or the said losses and said expenses incurred in connection with the notes of the members of said Credit Group provided said sale be made in the following manner: Before said notes and stock shall be advertised for sale, the party of the second part shall direct a communication in writing to either the Chairman or the Secretary of the aforesaid Credit Group, advising him of the existence of uncollected notes and/or losses in connection with notes of the members of said Credit Group; if either the said Credit Group, its members, or other persons do not, within ten days from the mailing of said communication, liquidate said uncollected notes and pay said losses, the party of the second part, its assigns or successors, may sell all of said uncollected notes and all of the stock in the Credit Corporation owned by members of the aforesaid Credit Group, at public auction for cash at the Court House door in Raleigh, North Carolina, after giving notice of said sale by posting a notice of same at the Court House door and three other public places in Wake County and by mailing a copy of said notice to the last known address of the owner of any stock certificate that is to be included in said sale; provided that, if the party of the second part elects to do so, it may sell, first, the stock of the members, who have not paid their notes or the collection of whose notes caused loss to the party of the second part because of attorney's fees or other expense; but the election of this option is not compulsory and shall not affect the rights and remedies of the party of the second part as hereinabove provided in this paragraph.

8. Certificates representing stock in the party of the second part, now owned or subsequently purchased by any member of the aforesaid Credit Group, shall be deposited with the President of the party of the second part as custodian of said stock; and an appropriate paper writing shall be furnished to each owner of said stock to evidence the aforesaid deposit on same.

9. If any member of the aforesaid Credit Group wishes to withdraw from said Group, he may do so by expressing in writing his desire to the Secretary of the Group and to the party of the second part, provided, however, that no member of the aforesaid Credit Group can withdraw therefrom at any time when the party of the second part holds an uncollected note signed by any member of said Group, unless said member desiring to withdraw shall execute a paper writing transferring and setting over to the party of the second part all right, title, and interest that said withdrawing member might own in any certificate of stock in the party of the second part.

IN WITNESS WHEREOF, the parties of the first part subscribe their names hereto on the dates indicated opposite each name:

NAME	ADDRESS	DATE OF SIGNATURE

U. S. GOVERNMENT PRINTING OFFICE: 1932

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C

REPRODUCTION AND HEALTH RECORDS OF THE BELTSVILLE HERD OF THE BUREAU OF DAIRY INDUSTRY

By FRED W. MILLER, *Senior Veterinarian and Physiologist*, and R. R. GRAVES, *Chief, Division of Breeding, Feeding, and Management, Bureau of Dairy Industry*

CONTENTS

	Page
Introduction	1
Fertility of cows and heifers	2
Services required for conception	3
Distribution of services	4
Comparison of cows and heifers	6
Prevalence of sterility	6
Ages at which sterility occurs	7
Fertility of bulls	7
Effect of season upon fertility	8
Comparison of young and aged bulls	8
Results of pregnancies terminated	9
Living calves, abortions, and calves born dead	10
Effect of age on calving efficiency	11
Causes and treatments of sterility	12
Removal of persistent corpora lutea	12
Causes and treatments of sterility—Con.	
Reducing ovarian cysts	13
Atresic follicles	13
Inflammation of genital organs	14
Exercise	14
Feeding sprouted oats to correct sterility	15
Control of abortion disease	17
Other abnormal conditions encountered, treatments, and fatalities	19
Nutritional disturbances	19
Foreign bodies	20
Lung troubles	20
Udder troubles	20
Injuries and lameness	20
Miscellaneous troubles	21
Discussion and summary	21

INTRODUCTION

Dairymen and others interested in dairy cattle have access to reproduction and disease records of certain individual animals, but such information on entire herds over considerable periods of time is rare.

The facts reported in this bulletin are from the records of a herd of dairy cattle made up of registered Holsteins, registered Jerseys, and grades of these two breeds. This herd is maintained by the Bureau of Dairy Industry at the United States Dairy Experiment Station at Beltsville, Md., for the purpose of conducting investigations in breeding, feeding, and management of dairy cattle. The information concerning breeding efficiency and calving efficiency during the 4-year period from May, 1922, to May, 1926, is taken from available records in the Bureau of Dairy Industry. All other information reported has been gathered and recorded by the writers during the 4-year period from May, 1926, to May, 1930.

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Experiments in animal pathology are not carried on at the Beltsville dairy station, but are conducted elsewhere by the Bureau of Animal Industry of the United States Department of Agriculture.[1]

The treatments and control measures for disease and sterility practiced with this experimental herd are those thought to be best suited to the conditions at the Beltsville station, and may or may not be best suited to conditions in other dairy herds. These treatments will not be discussed in detail.

From 1922 to 1926 all animals were handled together as one herd. For the purpose of this study the cows that were positive to the agglutination test for abortion disease will be referred to as the abortion-positive group and those that were negative to the test will be referred to as the abortion-negative group. In the spring of 1926, the herd was actually divided, and the two groups were separated by moving most of the abortion-positive animals to a new location about one-half mile away from the negative group. The records over this 8-year period (May, 1922, to May, 1930) afford an opportunity to compare some of the activities of the abortion-positive animals with those of the abortion-negative animals while they were in a herd together and while they were in separate herds.

FERTILITY OF COWS AND HEIFERS

In this publication, the term fertile, as applied to cows and heifers, is used to designate females that have conceived, regardless of whether they reproduce normal live calves.

The breeding efficiency of cows may be determined by either of the following methods: (1) By finding the percentage of females of breeding age that conceived; and (2) by finding the percentage of females actually bred that conceived.

In the Beltsville herd, the second method of determining breeding efficiency is more desirable to use than the first method, because of the fact that for experimental purposes animals are sometimes intentionally held open five to eight months after freshening. The first method of determining breeding efficiency may be used to obtain the economic status of a herd. The second method is used in this report.

The records show that in the period before the groups were separated, 268 abortion-negative cows and heifers were bred, and 232 conceived, representing an average breeding efficiency of 86.56 per cent; and 165 abortion-positive animals were bred, with 142 conceptions, an average efficiency of 86.06 per cent. After the groups were separated, the breeding of 368 abortion-negative animals resulted in 317 conceptions, an average of 86.14 per cent, and the breeding of 283 abortion-positive animals resulted in 245 conceptions, or 86.57 per cent.

Yearly fluctuations in breeding efficiency were similar in the two groups of animals. With the exception of the fiscal year 1922–23, the average breeding efficiency of the abortion-positive animals was

[1] All testing for tuberculosis in the Beltsville dairy herd has been done by the Tuberculosis Eradication Division of the Bureau of Animal Industry. Laboratory diagnoses, including all bacteriological, serological, and pathological work and the preparation of vaccines, have been done by the Pathological Division and the Bethesda Experiment Station, both of the Bureau of Animal Industry. The Zoological Division of the Bureau of Animal Industry has made numerous examinations of material from the herd for parasites. Members of these divisions of the Bureau of Animal Industry have given freely of their time and energy in studying individual cases, making physical examinations of animals, and advising in their care.

lower than that of the abortion-negative animals while both groups of animals were in the same herd. The average breeding efficiency of the abortion-positive animals remained lower in the first year after separation, but in each year since then it has been greater than that of the abortion-negative animals. When four years are taken as the unit of time, very little difference is found between the two groups of animals, either in the four years before or the four years after separation.

In this bulletin all animals being bred for the first conception are called heifers. All females being bred for the second or later conceptions are called cows. The 88 abortion-negative heifers in the herd before the groups were separated had a lower breeding efficiency than the cows, but the 146 heifers in the negative group after separation had a higher average breeding efficiency than the cows. It has been suggested that there seems to be more breeding troubles with heifers than with cows and that it would be natural to expect the heifers in the negative group to decrease its breeding efficiency. However, since a greater percentage of heifers than of cows conceived, it seems advisable to study the factors that affect conception in young and mature animals to determine whether or not heifers do have more breeding troubles than cows.

SERVICES REQUIRED FOR CONCEPTION

Table 1 shows that the average number of matings required for a conception in fertile abortion-negative cows was the same in the four years before as in the four years after separation of the groups. It was a trifle higher in fertile abortion-positive cows after the separation. In fertile abortion-negative heifers it was a little lower after separation. The increased number of matings required for a conception in abortion-positive heifers is of small significance, because of the few animals involved. The average number of services required for conception in all fertile animals in the herd was 2.88 before separation and 2.92 after separation. If services to sterile animals are included, the number of services for conception before and after separation was 3.94 and 3.48, respectively. The separation of the abortion-negative group from the abortion-positive group has had little or no effect on the number of matings required for conception.

TABLE 1.—*Data on services required for conception in fertile females, before and after separating the herd into two groups*

Class of females	Services to—		Conceptions in—		Services for conception in—	
	Cows	Heifers	Cows	Heifers	Cows	Heifers
Before separation:						
Abortion-negative	417	221	166	66	2.51	3.34
Abortion-positive	350	92	118	24	2.96	3.83
After separation:						
Abortion-negative	514	372	204	113	2.51	3.29
Abortion-positive	744	14	242	3	3.07	4.66

Heifers conceived less readily than cows. This is shown by the fact that heifers required an average of 0.62 more services for conception than cows. Fertile abortion-positive animals required an average of

0.33 more services for conception than fertile abortion-negative animals. The higher average in abortion-positive animals is accounted for by the fact that more services were required to produce conception after an abortion than after the birth of a normal calf. A comparison of Tables 1, 4, and 9 brings this fact out clearly.

DISTRIBUTION OF SERVICES

Approximately 42 per cent of the pregnancies in cows resulted from the first service, and in heifers the percentage was approximately 37 as shown in Table 2, which gives the distribution of services required by fertile females for conception. The percentage of conceptions resulting from the first service was greater in abortion-negative than in abortion-positive cows. About one-half as many conceptions in cows occurred in second matings as in first matings, and about one-half as many in third matings as in second matings. As compared with the cows, there were fewer conceptions in heifers on the first and second services, but more on the third to the eighth services. More than 72 per cent of the conceptions in all females occurred on or before the third service.

TABLE 2.—*Distribution of services required by fertile females in the abortion-positive, the abortion-negative, and heifer groups, for conception*

Number of service	Conceptions									
	Abortion-negative cows		Abortion-positive cows		All cows		All heifers		Total	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
First	156	44.06	147	40.83	303	42.43	78	36.79	381	41.14
Second	73	20.62	72	20.00	145	20.30	29	13.67	174	18.79
Third	37	10.45	43	11.94	80	11.20	36	16.98	116	12.52
Fourth	28	7.90	19	5.27	47	6.58	27	12.73	74	7.99
Fifth	18	5.08	22	6.11	40	5.60	13	6.13	53	5.72
Sixth	16	4.52	15	4.16	31	4.34	10	4.71	41	4.42
Seventh	6	1.69	11	3.05	17	2.38	6	2.83	23	2.48
Eighth	7	1.97	7	1.94	14	1.96	5	2.35	19	2.05
Ninth	2	.57	6	1.66	8	1.12	2	.94	10	1.07
Tenth to thirteenth	11	3.10	18	5.00	29	4.06	6	2.83	35	3.77

Table 3 shows that at the Beltsville station, where the breeding practice is somewhat less favorable for conception than in many commercial herds because of various kinds of experimental work, the chances are 94.2 in 100 that any female bred will eventually conceive, and that 38.79 per cent of females bred will conceive at the first service. After failure to conceive on the first service, the chances are 90.9 in 100 for eventual conception, and that 29 per cent will conceive at the second service. Table 3 also shows the chances of conception after the second and each successive mating to the tenth. The animals bred between 11 and 20 times are grouped in one class, and those bred between 21 and 30 times are grouped in another class. The chances for conception and for failure to conceive are about equal after the tenth service. The percentage of animals conceiving at each successive mating after the first service gradually decreased until the tenth service, after which there was much fluctuation.

TABLE 3.—*Distribution of matings for conception, and the probability of conception for each service and additional services*

Number of service	Females bred	Females conceiving		Females discarded as sterile		Chances in 100, immediately before service indicated, of females ever conceiving
	Number	*Number*	*Per cent*	*Number*	*Per cent*	*Number*
First	982	381	38.79	1	0.10	94.2
Second	600	174	29.00	2	.33	90.9
Third	424	116	27.35	2	.47	87.5
Fourth	306	74	24.18	4	1.30	83.3
Fifth	228	53	23.24	3	1.31	79.4
Sixth	172	41	23.83	2	1.16	74.5
Seventh	129	23	17.82	5	3.87	67.5
Eighth	101	19	18.81	2	1.98	63.4
Ninth	80	10	12.50	3	3.75	56.3
Tenth	67	6	8.95	3	4.47	52.3
Eleventh to twentieth	58	27	46.55	21	36.20	50.0
Twenty-first to thirtieth	10	2	20.00	8	80.00	20.0

Diagnosis of permanent sterility was made only when the animals were slaughtered and the genital organs carefully examined. Decisions were not made because of the number of services. An example is that of a cow that did not show œstrum and was not bred over a period of two years. When she was slaughtered the genital organs were found to be so diseased that conception was impossible. The cows bred from 2 to 30 times without conception perhaps were just as sterile on the first as on the last service, but a definite decision concerning their condition was reached only when the animal was slaughtered.

Data on the entire herd, as presented in Table 4, indicate that more services were required on an average for conception after abortion than after the birth of a normal calf. Data from abortion-positive animals show similar results. In abortion-negative cows, however, fewer services were required for conception after abortion than after normal calving. This seems to indicate that abortions caused by the microorganism, *Brucella abortus*, are more harmful to the genital organs than normal calvings.

TABLE 4.—*Number of services for conceptions after normal calvings and after abortions*

Class of females	Conceptions	Services	Services for a conception
Abortion-negative group:			
Cows bred after normal calving	179	517	2.88
Cows bred after aborting	16	39	2.43
Abortion-positive group:			
Cows bred after normal calving	276	772	2.79
Cows bred after aborting	99	360	3.63
Entire herd:			
Cows bred after normal calving	455	1,289	2.83
Cows bred after aborting	115	399	3.46

COMPARISON OF COWS AND HEIFERS

The average number of services required for conception in abortion-negative heifers was greater than the number required in abortion-negative cows throughout the 8-year period, except during the fiscal years 1925–26 and 1927–28. Only 67 per cent of the conceptions in heifers occurred on or before the third service, as compared with 73 per cent in cows. The average number of services for heifers was greater than for cows. A larger percentage of heifers than of cows eventually became pregnant.

PREVALENCE OF STERILITY

An attempt is made in this work to ascertain the influence of abortion infection on permanent sterility. Other phases of the subject are discussed in detail on page 12. The records show that 5 abortion-negative and 18 abortion-positive animals became permanently sterile before the groups were separated, and that 10 abortion-negative and 27 abortion-positive animals became permanently sterile after separation. The number of females of breeding age that were in the two herds when the separation was completed in October, 1926, and the occurrence of permanent sterility, by 2-year periods, is shown in Table 5. The data show that 19 of the abortion-positive animals became sterile in the two years following separation, and only 4 abortion-negative animals became sterile in this period. Of the original animals left in these two herds in the third and fourth years after separation, 6 animals, or 13.63 per cent, in the abortion-negative group, and 8 animals, or 12.12 per cent, in the abortion-positive group became sterile.

TABLE 5.—*Permanent sterility in the original abortion-negative and abortion-positive females since the separation of the two groups*

Group	Total females	Females sterile first 2 years		Total females remaining at end of 2 years	Females sterile second 2 years		Total females remaining at end of 4 years
	Number	*Number*	*Per cent*	*Number*	*Number*	*Per cent*	*Number*
Abortion-negative females of breeding age in October, 1926 [1]	52	4	7.69	44	6	13.63	33
Abortion-positive females of breeding age in October, 1926 [2]	101	19	18.81	66	8	12.12	45

[1] Only those animals that have remained negative to the agglutination test are included here.
[2] Only those animals that were in the abortion-positive herd in October, 1926, are included here.

The fact that the percentage of permanent sterility was greater in abortion-positive animals before the separation of the groups and for two years following separation than during the third and fourth years after separation, indicates that the bacteria causing abortion disease are more virulent when both susceptible and infected animals are kept together, and that the disease when virulent causes sufficient damage to the genital organs to produce sterility. The fact that the percentage of permanent sterility in the abortion-positive animals had decreased during the third and fourth years after separation indicates that abortion disease, when not in so virulent a form has less influence in causing sterility. Factors other than those causing abortion, however, operate both in abortion-negative and abortion-positive animals to produce sterility.

AGES AT WHICH STERILITY OCCURS

The frequency with which sterility occurred at various ages is shown in Table 6. There was very little sterility in heifers and young cows. A marked increase was noticed when cows became mature, and from six years on there was a steady increase in sterility. Of the 242 heifers bred, 5.27 per cent became permanently sterile before reaching 5 years of age, 11.98 per cent before reaching 8 years of age, and 16.94 per cent before reaching 10 years of age. The two cows bred when 13 years of age were sterile.

TABLE 6.—*Age distribution at which permanent sterility occurred in the Beltsville herd*

Age (years)	Females	Sterile females		Age (years)	Females	Sterile females	
	Number	*Number*	*Per cent*		*Number*	*Number*	*Per cent*
2[1]	242	6	2.47	9	51	6	11.76
3[2]	164	3	1.83	10	20	8	40.00
4	173	4	2.31	11	16	6	37.50
5	146	5	3.42	12	4	3	75.00
6	104	6	5.77	13	2	2	100.00
7	81	5	6.17	14	1	0	0.00
8	76	6	7.89				

[1] Two-year olds as given here include those animals bred at 15 to 24 months of age.
[2] Only animals bred are included in this table. All animals were on official test during their first lactation, and some of them were not bred at 3 years of age. This makes a large decrease in the number of animals between the 2-year and the 3-year class.

FERTILITY OF BULLS

In the breeding experiments at Beltsville, sires 6 years old or older are used more than young bulls. These old sires are handled, as

FIGURE 1.—Bull exerciser at Beltsville, Md.

nearly as possible, in a manner to keep them constantly at their optimum efficiency. Regular exercise and the addition of sprouted oats to the ration have been helpful in maintaining this efficiency.

In addition to increased activity and normality of the spermatozoa of bulls fed sprouted oats, the organs of elimination seem to be healthier than in animals not eating sprouted oats. The equivalent of 5 pounds of dry oats were fed when sprouted, each day. The oats were fed when the sprouts were one-fourth to one-half inch long, and a mass of white roots was present.

Regular exercise seems to have a more beneficial effect on the genital functions of bulls than any other treatment, probably because exercise keeps the body muscles in normal tone and the animal is more vigorous and active as a result. Bulls are also more docile when exercised.

The animals are hitched to a circular exerciser and forced to walk for approximately 1½ hours each day. It is thought there is less danger of injury with this method of exercising than with treadmills.

Microscopical examinations of the semen of herd sires were made from time to time as a check on their breeding efficiency. Aged sires were no longer fruitful after the activity of their spermatozoa fell below 50 per cent. Attempts to rejuvenate these animals did not restore the normal functions of their genital organs.

The details of the morphological and physiological studies of spermatozoa from bulls exercised, from those on various nutritional rations, from aged sires, and from those in which rejuvenation was tried, are not included in this bulletin.

EFFECT OF SEASON UPON FERTILITY

A summary of the records of 22 fertile bulls mated with fertile cows from January 1, 1926, to December 31, 1929, inclusive, are presented in Table 7. On an average more services were required for a conception during July, August, and September than during other months of the year. The average number of services required for a conception during these three months was 4.05; for October, November, and December, the average was 2.80; the average during January, February, and March was also 2.80, while the average for April, May, and June was practically the same—2.81. This is contrary to what might be expected. The period of lowest fertility as shown here would be the normal breeding season for the American bison, as reported by Marshall.[2] It is suggested that the hot weather influences the functioning of the genital organs adversely. Increased genital efficiency seems to have been associated with the advent of autumn.

TABLE 7.—*Summary of records of the relation of season to fertility of 22 fertile bulls for four years.*

Month	Services	Conceptions	Average services for a conception	Month	Services	Conceptions	Average services for a conception
January	150	57	2.63	July	124	29	4.28
February	109	32	3.41	August	123	34	3.62
March	139	53	2.62	September	122	28	4.36
April	123	36	3.42	October	128	44	2.91
May	130	53	2.45	November	118	36	3.28
June	124	45	2.75	December	149	61	2.44

COMPARISON OF YOUNG AND AGED BULLS

From January 1, 1926, to April 10, 1930, 26 different bulls were used as herd sires in various breeding experiments at the Beltsville station, 10 of them in 1926, 12 in 1927, 20 in 1928, and 1929, and 17 in the first three months of 1930. For comparison the records of the breeding efficiency of these 26 bulls are shown in Table 8. All animals more than 6 years of age are classed as mature bulls, and those less than 6 years of age are classed as young bulls. Eight of the bulls were mature before being used in this herd. Of the 18 young bulls used, 2 became mature within the time these records were made. The records of these 2 bulls made before they were 6 years old appear in the young-bull class, and their records after 6 years of age appear in the mature-bull class. They are Nos. 9 and 10 in the mature class and Nos. 11 and 12 in the young-bull class.

[2] MARSHALL, F. H. A. THE PHYSIOLOGY OF REPRODUCTION * * * 2d and rev. ed. 770 pp., illus. London, New York, [etc.] 1922

TABLE 8.—*Comparison of the breeding efficiency of mature and young bulls*

MATURE BULLS

Bull No.	All services			Services to fertile females only		
	Services	Conceptions	Services for a conception	Services	Conceptions	Services for a conception
1	82	11	7.45	38	11	3.45
2	121	19	6.36	94	19	4.94
3	196	27	7.25	158	27	5.85
4	235	40	5.87	224	40	5.60
5	86	26	3.30	86	26	3.30
6	268	77	3.48	226	77	2.93
7	108	39	2.76	98	39	2.51
8	44	12	3.66	41	12	3.41
9	131	27	4.85	112	27	4.14
10	32	11	2.91	32	11	2.91
Total or average	1,303	289	4.50	1,109	289	3.83
YOUNG BULLS						
11	74	29	2.55	66	29	2.27
12	108	31	3.48	58	31	1.87
13	76	28	2.71	72	28	2.57
14	85	29	2.93	61	29	2.10
15	89	34	2.61	73	34	2.14
16	62	19	3.26	53	19	2.78
17	85	25	3.40	85	25	3.40
18	49	27	1.81	46	27	1.70
19	48	21	2.28	43	21	2.04
20	12	3	4.00	12	3	4.00
21	7	5	1.40	7	5	1.40
22	21	9	2.33	14	9	1.55
23	47	14	3.35	46	14	3.28
24	8	6	1.33	8	6	1.33
25	12	5	2.40	9	5	1.80
26	1	0	0	1	0	0
27	1	1	1.00	1	1	1.00
28	1	1	1.00	1	1	1.00
Total or average	786	287	2.73	656	287	2.28
Total or average, all bulls	2,089	576	3.62	1,765	576	3.06

A total of 576 conceptions resulted from 2,089 matings, an average of 3.62 services for each conception. If services to cows that remained sterile are omitted, there were 1,765 matings with fertile cows, which resulted in 576 conceptions, or 3.06 services for each conception. More services were required for conception when mature bulls were used than when young bulls were used. There was also a considerable variation between bulls of the same age, as can be readily seen in Table 8.

RESULTS OF PREGNANCIES TERMINATED

Only those pregnancies which terminated within the period of this study are considered here. The pregnancies terminated in living calves, abortions, and dead calves. When a fetus was born alive, normally developed, able to stand and nurse its dam, it was designated as a living calf. After the separation of the abortion-negative and abortion-positive groups all fetuses delivered which were apparently lacking in intrauterine development were termed abortions. The mummified fetuses in both the abortion-negative and abortion-positive herds were classified as calves born dead. Other calves were born dead after a normal period of gestation and were fully developed. The majority of these died during delivery, some were unavoidably killed by the attendants during birth, and some seem to have been dead before labor began.

LIVING CALVES, ABORTIONS, AND CALVES BORN DEAD

Table 9 shows the results of pregnancies terminated. Throughout the 8-year period, the abortion-negative animals produced more living calves, fewer abortions, and more dead calves than the abortion-positive animals. The percentage of living calves in the abortion-negative group decreased and the percentages of abortions and dead calves increased after the separation, and in the abortion-positive herd the percentages of living calves increased, abortions decreased, and dead calves increased. The increase in percentage of calves born dead can be partly explained by the fact that a number of heifers in the abortion-negative group had genital tracts which were too small to deliver live calves, and some of the older cows in the abortion-positive group became sluggish, relaxed, and listless near calving time and delivered dead calves.

TABLE 9.—*Results of pregnancies terminated*

Item	Before the separation					After the separation				
	1923[1]	1924[1]	1925[1]	1926[1]	Total	1927[1]	1928[1]	1929[1]	1930[1]	Total
Abortion-negative animals:										
Females of calving age in herd—Number	72	70	95	57	------	74	80	93	116	------
Pregnancies terminated—do	48	58	54	34	194	48	52	69	87	256
Living calves—do	39	54	50	32	175	39	42	59	74	214
Living calves—Per cent	81.25	93.10	92.59	94.11	90.20	81.25	80.76	85.50	85.05	83.59
Abortions—Number	8	3	1	1	13	2	3	6	8	19
Abortions—Per cent	16.66	5.17	1.85	2.94	6.70	4.16	5.76	8.69	9.19	7.42
Dead calves—Number	1	1	3	1	6	7	7	4	5	23
Dead calves—Per cent	2.08	1.72	5.55	2.94	3.09	14.58	13.46	5.79	5.74	8.98
Abortion-positive animals:										
Females of calving age in herd—Number	38	47	37	94	------	99	86	83	79	------
Pregnancies terminated—do	29	25	30	67	151	61	61	63	61	246
Living calves—do	19	16	20	35	90	32	47	46	47	172
Living calves—Per cent	65.51	64.00	66.66	52.23	59.60	52.45	77.04	73.01	77.04	69.91
Abortions—Number	10	8	9	31	58	26	9	12	13	60
Abortions—Per cent	34.48	32.00	30.00	46.26	38.41	42.62	14.75	19.04	21.31	24.39
Dead calves—Number	0	1	1	1	3	3	5	5	1	14
Dead calves—Per cent	0.00	4.00	3.33	1.49	1.98	4.91	8.19	7.93	1.63	5.69

[1] Year ended May 31.

Before the groups were separated all abortions in the abortion-negative animals were single births, and one of the abortions in the abortion-positive animals was twins. Of the 19 abortions in the abortion-negative group after separation, 6 were twins and 13 were single births. One of the 60 abortions in the abortion-positive group was twins.

A complete record of bacteriological and pathological studies of aborted fetuses produced by abortion-negative animals in the period before separation is not available. In the period after the groups were separated such studies revealed the presence of *Bacillus pyogenes* in one case, *B. coli* in one case, streptococci in one case, and no *Brucella abortus* or other bacteria in the other 16 cases of abortion in the abortion-negative group. The cause of the abortions in these 16 cows is unknown. One cow in the abortion-negative group has aborted three times, and it was in her last abortion that streptococci were found. The *B. coli* were found in an abortion of twins and the *B. pyogenes* in an abortion from an old cow.

The abortions that occurred in the abortion-positive group have been recorded by 6-month periods to permit of a comparison of the abortions in cows that were in the positive group at the time of the

separation with those of cows that were added later, from the negative group, as they became positive. From May 11 to December 31, 1926, inclusive, there were 18 abortions. Of these 18 cases, 11, or 61.11 per cent, were from cows that were in the positive groups at the time of the separation, and 7, or 38.89 per cent, were from animals that were added to the group later. From January 1 to June 30, 1927, inclusive, 13 abortions occurred. Nine of these, or 69.23 per cent, were from cows of the original positive group, and 4, or 30.77 per cent, were from animals added later. From July 1 to December 31, 1927, inclusive, there were only 3 abortions. One of these was from a cow of the original positive group and 2 were from animals added later. Only 2 abortions occurred during the next six months, 1 from a cow belonging to the original abortion-positive group and 1 from an animal added later. In the period from July 1 to December 31, 1928, there were 4 abortions from cows of the original group and 3 from animals added to the group later. From January 1 to June 30, 1929, there were 9 abortions. Two of these, or 22.22 per cent, were from cows of the original group, and 7, or 77.78 per cent, were from animals added later. From July 1 to December 31, 1929, 6 abortions occurred. One abortion, or 16.67 per cent, was from a cow belonging to the original group, and 5, or 83.33 per cent, were from animals added to the group later. In the first six months in 1930, there were 4 abortions in animals that had been added, and none in animals of the original group. In this 4-year period 59 abortions occurred, and of these, 26 were in animals in the abortion-positive group at the time of the separation and 33 were in animals that became positive later. Of the 26 abortions in the original positive group, 20 occurred in the first year after the separation. These data may indicate that the abortion infection loses its virulence when abortion-positive cows are kept by themselves, or, as appears more likely, the abortion-positive cows develop a certain resistance or tolerance to the infection that is sufficient to enable them to retain the fetus to full term.

EFFECT OF AGE ON CALVING EFFICIENCY

The distribution of calving efficiency by age of dam and number of pregnancy is shown in Table 10.

TABLE 10.—*Distribution of pregnancies terminated before and after the separation of the abortion-positive from the abortion-negative cows*

Class of cows and number of pregnancy	Before separation						After separation					
	Living calves		Abortions		Dead calves		Living calves		Abortions		Dead calves	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Abortion-negative:												
First	41	83.67	4	8.16	4	8.16	73	78.49	6	6.45	14	15.05
Second	42	93.33	3	6.67	0	0.00	41	87.23	4	8.51	2	4.26
Third	34	89.47	3	7.89	1	2.63	29	90.62	1	3.12	2	6.25
Fourth	24	100.00	0	0.00	0	0.00	23	95.83	1	4.17	0	0.00
Fifth	9	75.00	2	16.67	1	8.33	19	82.60	2	8.70	2	8.70
Later	25	96.15	1	3.85	0	0.00	29	78.38	5	13.51	3	8.11
Total	175	90.21	13	6.70	6	3.09	214	83.59	19	7.42	23	2.98
Abortion-positive:												
First	11	39.29	17	60.71	0	0.00	8	28.57	19	67.86	1	3.57
Second	14	56.00	9	36.00	2	8.00	27	54.00	20	40.00	3	6.00
Third	15	60.00	10	40.00	0	0.00	42	79.24	10	18.87	1	1.89
Fourth	14	60.87	9	39.13	0	0.00	35	85.36	4	9.76	2	4.88
Fifth	11	68.75	4	25.00	1	6.25	24	77.42	4	12.90	3	9.68
Later	25	73.53	9	26.47	0	0.00	36	83.72	3	6.98	4	9.30
Total	90	59.60	58	38.41	3	1.99	172	69.92	60	24.39	14	5.69

In the abortion-negative animals the greatest percentage of living calves were born of the fourth pregnancies. The same is true of abortion-positive animals after the separation of the groups, although older animals produced more living calves before separation. The smaller percentages of live calves in earlier pregnancies of the abortion-negative animals are accounted for by the larger number of calves born dead (the reason for the number of calves born dead in first pregnancies has been given) and the smaller percentages of live calves in the latter pregnancies were a result of the larger number of abortions.

The greatest percentages of abortions in the abortion-negative animals, after the separation of the groups, were after the fifth pregnancies. In the abortion-positive animals the greatest percentage of abortions was during the first pregnancies. A sharp decrease in the percentage of abortions occurred during the second pregnancies, followed by a gradual decrease in succeeding gestations.

A slight error may have entered Table 10, because a few grade cows, whose ages were unknown, had been purchased early in the history of the herd. The results of their gestations before the separation of the groups were counted with the later pregnancies only. The age and number of pregnancies of all animals in the groups after the separation were known.

CAUSES AND TREATMENTS OF STERILITY

Sterility refers to the loss of reproductive power, and may be temporary or permanent. Aside from being caused by obesity, starvation, malformations, and systemic diseases, sterility may be caused by morbid conditions of the genital organs, and it occurs also in some animals where no signs of pathological changes can be found.

Temporary sterility is the term used in this publication to describe the condition of an animal that conceives after four or more matings. The term "permanent sterility" is applied, after exhausting present knowledge of diagnosis and treatment, to those animals that do not conceive. Sometimes as many as 20 services over periods of more than two years have failed.

Pathological conditions of the genital organs readily recognized in the living animal were persistent corpora lutea, ovarian cysts, atresic follicles, and some inflammatory changes in various parts of the genital organs.

REMOVAL OF PERSISTENT CORPORA LUTEA

Persistent corpus luteum prevents œstrum in the cow. When a barren cow does not show œstrum for a long period the condition of the animal may be interpreted as being similar to pseudopregnancy. The retained corpus luteum interferes with normal conception. Usually when the corpus luteum is removed from the ovary the genital organs begin to function, œstrum showing in from 3 to 10 days. Sometimes the signs of œstrum are not prominent enough to be noticed, and the results of removal of the corpus luteum may be misinterpreted.

Results of the removal of persistent corpora lutea on conception are shown in Table 11.

TABLE 11.—*Results of removing persistent corpora lutea*

Class of cows	Cows	Days without œstrum	Conceived on first service	Conceived later	Not yet pregnant	Died, not conceiving
Abortion-negative	38	80	21	11	3	3
Abortion-positive	26	78	11	11	2	2
Total	64	[1] 79	32	22	5	5

[1] Average.

It has been the practice at Beltsville to breed cows during the first œstrum observed following the removal of corpora lutea. Fifty per cent of those bred at the first œstrum following the removal became pregnant, and 34 per cent conceived when bred during later œstrums. The data in Table 11 show that when persistent corpora lutea are removed the genital organs start to function normally and that it is advisable to mate the cow during the first œstrum.

REDUCING OVARIAN CYSTS

Ovarian cysts seem to manifest themselves in two ways: (1) By causing irregular œstrums, and (2) by causing irregular œstrums accompanied by nymphomaniac symptoms. The first type of cysts yield readily to treatment by rupturing, while the second type does not respond so readily to this treatment.

Six abortion-negative and 13 abortion-positive cows have been affected with ovarian cysts since the groups were separated. One abortion-negative and two abortion-positive cows were affected more than one sexual season; therefore, 22 cases of ovarian cysts were observed in 19 cows.

Of the 22 cases, 4 appeared in the second sexual season, 5 in the third, 2 in the fourth, 6 in the fifth, 3 in the sixth, 1 in the seventh, and 1 in the ninth sexual season.

Seventeen cases of ovarian cysts appeared while the cows were on official test and five cases while the cows were not on official test. All of the cows seemed normal and in good flesh before the ovarian cysts appeared. The cysts were noted during 8 of the first 10 months of the lactation period.

There were eight cases of irregular œstrums with very little or no excitement, all in the second and third sexual seasons, and all responded to treatment by rupture of the cysts.

Nymphomaniac symptoms were present in 14 cases, all occurring after the second sexual season and only 5 of these animals responded to treatment.

ATRESIC FOLLICLES

When a ripe Graafian follicle fails to rupture and release the ovum, and is reabsorbed, it is called an atresic follicle. The animal shows the same outward symptoms that are shown when an ovum is released normally. Obviously conceptions do not occur following matings at these times. The frequency of this condition in cattle is not known. It has been found in four living heifers and in one dead cow in the Beltsville dairy herd.

INFLAMMATION OF THE GENITAL ORGANS

Inflammation of the tubular portions of the genital organs may be recognized in the living animal when it is severe enough to cause gross changes in the tissues or secretions. Often the inflammation is so mild that it can not be detected readily, or it may have subsided, and the damage done is not easily recognized. Sometimes the inflammation spreads and causes damage to other organs, or it may spread from other organs to the genital organs and form adhesions between the organs involved, or tumors that interfere with the normal functions of the genital organs. Abscesses involving a part or all of the genital organs may develop, causing temporary sterility and in many cases permanent sterility. Injuries and the common pus-forming bacteria are responsible for most of these pathological inflammations. The treatment administered is the same as that for similar conditions in other parts of the body, in so far as the location and morphology of the organs allow. In the abortion-negative group 11 cases have been found, and in the abortion-positive group 50 cases have been encountered, since the separation of the groups.

EXERCISE

Inflammation, ovarian cysts, excess fat, bodily inactivity, or old age may cause a loss of tone in the muscles and ligaments supporting the genital organs. Sometimes this lack of tone extends to the voluntary muscles of the body. The lack of tone in many cases is due primarily to senility, which is sometimes premature, or to asthenia. The weakness may be general, but is more often restricted to the genital organs.

The influence of exercise in correcting certain forms of sterility in 19 cows is shown in Table 12. Improvement in the condition of the genital organs was noted in all of the cows, except in the one affected with edema of the walls of the uterus, when the cows were forced to take exercise by being driven on a track for approximately two hours a day for periods varying from 30 to 156 days. It seems that forced exercise was directly responsible for the improvement that allowed normal conceptions in 6 of the 19 animals. Five more conceived later, and 8 remained sterile.

TABLE 12.—*Influence of forced exercise on sterility in cows*

Cow No.	Days exercised	Services before start of exercise	Services after start of exercise	Time between start of exercise and conception	Disturbances preventing conception
				Days	
441	136	11	3	58	Lack of muscular tone.
477	156	14	3	49	Do.
490	152	9	6	(1)	Do.
426	64	5	2	26	Tumors and lack of muscular tone.
609	65	13	2	110	Lack of muscular tone.
273	105	8	4	(1)	Do.
150	105	7	8	223	Do.
457	47	8	1	38	Do.
468	156	0	0	(1)	Inflammation of uterus, tubes, and ovaries, pus.
442	65	7	1	(1)	Inflammation of uterus.
631	105	0	7	(1)	Inflammation of uterus, abscess.
651	30	1	6	167	Inflammation around ovaries.
264	74	11	2	(1)	Edema walls of uterus.
162	156	6	4	(1)	Ovarian and vaginal cysts, inflammatory changes.
606	155	8	5	133	Ovarian cysts, soft uterus.
156	105	2	1	148	Ovarian cysts
626	155	9	8	(1)	Heifer, apparently normal.
644	65	5	2	53	Apparently normal.
652	105	6	9	292	Do.

[1] No conception.

FEEDING SPROUTED OATS TO CORRECT STERILITY

In cases of sterility where no indication of pathological changes can be found in the genital organs and conception does not take place, the condition may be called a functional disturbance. The definite cause of such sterility is unknown. As previously mentioned, experiments including the feeding of sprouted oats are being carried on at the station in the study of these functional disturbances of the genital organs.

It has been found that for this purpose the oats are most effective when germinated until the sprouts extend through the grains from one-fourth to one-half inch and a mass of white roots is formed. Cattle eat oats germinated to this stage more readily than when the sprouts are longer. Quantities of sprouted oats equivalent to 2½ to 5 pounds of dry oats have been fed daily during the feeding period.

In sprouting oats, it has been found advantageous to place the desired amount of dry oats in a sack and soak for 24 hours in a tub or barrel of water to which a small amount of formalin (1 ounce of formalin to 50 gallons of water) has been added for the purpose of preventing mold. After the sack of oats is removed from the water, it is placed on the floor for 24 hours during warm weather and for 48 hours during cold weather, then the oats are spread in the pans or trays of an ordinary sprouter, or placed in drums, or spread to a thickness of about 2 inches on a clean floor. It requires approximately three days to produce sprouts one-fourth to one-half inch long from oats in this stage. During the sprouting period the oats must be kept moist, care being taken to prevent too much moisture in one place and drying in another. The oats seem to sprout more rapidly and evenly when kept at a temperature of 75° to 80° F. They may be fed as soon as the desired growth is obtained.

The advantage of sprouting oats in pans is that it facilitates feeding the desired amount to the animal. The advantage of a drum sprouter, where the oats are transferred from one drum to a similar drum on a lower level, is that the oats are easier to handle during the sprouting period. The turning of the oats breaks up mold growths, it also allows air to come in contact with more of the oat grains, and it helps to keep an even moisture throughout the mass of sprouting grain.

The plan has been to feed sprouted oats to cows that had been bred without results for some time but showed no pathological conditions, and to feed sprouted oats to heifers for approximately 90 days before they became of breeding age. A thorough physical examination is made of each animal to determine whether there are any pathological conditions that might prevent conception.

The experiment requiring the comparison of the results of genital activity of animals fed sprouted oats and animals not fed sprouted oats has not progressed far enough to be reported. In the results recorded, it has been assumed that animals which had to be bred four or more times after they began to eat sprouted oats were not benefited by this treatment.

Table 13 is a summary of the breeding records of animals that appear to have been benefited by sprouted oats, as shown by the small number of services required for conception after the animals were started on sprouted oats as compared with the number of sterile matings before sprouted oats were fed.

TABLE 13.—*Influence of sprouted oats fed to apparently normal animals that were temporarily sterile*

Class and cow No.	Services		Time between start of feeding sprouted oats and conception	Class and cow No.	Services		Time between start of feeding sprouted oats and conception
	Before start of feeding	After start of feeding			Before start of feeding	After start of feeding	
Abortion-negative:			*Days*	Abortion-positive:			*Days*
268	2	2	33	457	5	3	71
291	2	2	34	426	16	2	42
467	7	1	19	488	7	1	48
416	6	2	45	457	9	3	77
496	5	1	24	609	13	2	123
601	3	1	31	644	5	2	60
424	5	1	19	625	1	1	68
290	3	3	91	651	4	3	100
819	4	1	53				
831	5	1	24				
631	2	1	5				

In addition to the animals listed in Table 13, 11 abortion-negative cows that had been bred an average of 4.45 times were fed sprouted oats, but it was found upon examination that these animals had conceived on an average of 12.91 days before the feeding began, also 3 abortion-negative heifers that had been bred 4 times each before being placed on the sprouted-oat ration were found to have conceived on an average of 12.33 days before the feeding began. Eleven abortion-positive cows that had been bred an average of 4.63 times were fed sprouted oats, but it was found upon examination that these animals had conceived on an average of 28.09 days before feeding began, also 2 abortion-positive heifers that had been bred 3 and 4 times, respectively, before being placed on the sprouted-oat ration were found to have conceived 21 and 24 days, respectively, before feeding began. It seems probable that sprouted oats may contain a vitamin, or a hormone in quantities sufficient either to prevent early abortions or reabsorption of the embryo, or to aid implantation of the newly fertilized ovum.

Three abortion-negative cows were fed sprouted oats before being bred. One of these cows conceived on the first mating, and the other two required two services each. These cows were fed 20 to 137 days, respectively, before becoming pregnant. Four abortion-positive cows were placed on the sprouted-oat ration before being bred. Two of these cows conceived on the first service, and the other two required two and three services, respectively. These cows were fed 15 to 46 days before conceiving.

Thirty abortion-negative heifers were fed sprouted oats before being bred. Twenty-four of these were fed approximately 90 days before they reached breeding age, and 6 were fed a shorter time. Seventeen conceived at the first mating, 4 at the second, and 9 at the third, making an average of 1.73 services for initial conception. One abortion-positive heifer which was fed sprouted oats before being bred, conceived at the first service.

In cases where more than three services were required for conception after the feeding of oats started, the conception was not attributed to any benefit derived from the use of sprouted oats. Cases in this class are described below.

Three abortion-negative and 8 abortion-positive cows whose genital organs appeared normal required four or more services for conception after being fed sprouted oats, also 18 abortion-negative and 2 abortion-positive heifers having normal genital organs required four or more services for conception.

Sprouted oats were fed to 3 abortion-negative and 16 abortion-positive cows which also received other treatment while showing pathological changes in the genital organs. One of the abortion-negative cows and 7 of the abortion-positive cows became pregnant; the others remained sterile.

In summarizing the results of feeding sprouted oats it appears that 57 females were directly benefited and 31 were not benefited, as judged by the number of services required to produce conception. It is not definitely known whether feeding sprouted oats was beneficial to the 27 females that conceived to a service just previous to the start of feeding. There is no evidence to show that sprouted oats were helpful to the cows showing pathological changes in the genital organs.

CONTROL OF ABORTION DISEASE

Abortion disease was very seriously interfering with the progress of the breeding and nutritional investigations in the Beltsville herd; therefore an attempt was made to control the disease by separating the abortion-positive animals from the abortion-negative animals and handling them in two separate herds. Diagnosis of the disease was made by the agglutination test.

In May, 1926, 71 abortion-positive females were moved to new quarters approximately one-half mile from the original barns. Because of certain experimental work that was in progress 14 abortion-positive females were kept in one of the original barns, but separate from abortion-negative animals, until October, 1926, when they were moved to the new quarters and placed with the other abortion-positive animals.

After the abortion-positive animals were moved, the barns were thoroughly scrubbed with hot water and soap and a disinfectant applied. The yards were scraped, and the scrapings and all litter were moved to cultivated fields. Two crews have been maintained, one for the abortion-negative herd, the other for the abortion-positive herd.

The same bulls have been used on abortion-negative and abortion-positive females with no apparent bad results to date. Breeding has always been done on neutral ground. Calves from the abortion-positive cows have been kept on the abortion premises and fed milk from the abortion-positive herd until they were 60 days old; then they were fed milk from the abortion-negative herd until they were moved to the negative premises 10 days later. All straw, manure, and dirt were cleaned from their bodies before they were placed in the barns on the negative premises. Only milk from the abortion-negative herd has been fed to animals at the abortion-negative part of the farm. All litter and waste from the abortion-positive herd has been moved to cultivated fields or placed on the abortion-positive premises. However, milk from the abortion-positive herd has been brought to the milk-handling room on the abortion-negative part of the farm,

and official testing of milk from abortion-positive animals has been done in the same building in which the milk-handling or dairy room is located.

Between May, 1926, when some of the abortion-positive animals were separated from the original herd, and October, 1926, when the remainder of the abortion-positive animals were moved away from the original barns, 24 animals in the abortion-negative herd reacted to the agglutination test and were added to the abortion-positive herd. Some of these animals may have been infected before the herds were separated, some may have become infected through calf manure that was placed on a pasture by mistake, and some may have become infected through the abortion-positive animals remaining at the original barns during the interval. In the following two years eight abortion-negative animals became abortion-positive and were moved from the original barns. Eleven animals became infected during the third year. During the fourth year no abortion infection occurred in the negative herd. A total of 43 females have become positive to the agglutination test for abortion disease since the herds were separated in May, 1926.

Possible sources of infection entering the abortion-negative herd have been the handling of the milk from the abortion-positive herd on the abortion-negative farm, the delivering of feeds and hauling of manure from the two herds by the same men and equipment; visitors coming into the abortion-negative herd after having been among the animals of the abortion-positive herd. The use of straw from dairy districts where abortion disease might exist is also a possible source of infection.

When infection does enter the abortion-negative herd, it takes some time to eliminate the disease again. An example of the difficulty encountered in preventing the spread of infection is that of a heifer which aborted in the pasture of the abortion-negative herd before it was known that she was infected.

The agglutination test was applied to the abortion-negative herd every 60 days during 1926, twice a year during 1927 and 1928, and every 60 days during 1929 and up to July, 1930.

Table 14 shows the number of animals that became infected in the abortion-negative herd in a 4-year period. A greater number of cows became positive immediately after the separation than at any time later. The number of females of breeding age has steadily increased in the abortion-negative herd.

TABLE 14.—*Distribution of abortion-positive animals removed from the abortion-negative herd in a period of four years*

Date animals were moved	Females in negative herd that became infected	Females that remained in negative herd	Date animals were moved	Females in negative herd that became infected	Females that remained in negative herd
May, 1926	85	71	October, 1928	3	107
June, 1926	6	73	January, 1929	5	113
July, 1926	9	65	February, 1929	1	109
September, 1926	7	65	March, 1929	2	108
November, 1926	1	78	May, 1929	1	118
March, 1927	1	81	June, 1929	2	120
June, 1927	1	80	May, 1930	0	139
May, 1928	4	107			

OTHER ABNORMAL CONDITIONS ENCOUNTERED, TREATMENTS, AND FATALITIES

Disease or abnormal conditions encountered in the Beltsville dairy herds since the separation may be classed under the following headings: Nutritional disturbances, foreign bodies, lung troubles, injuries and lameness, miscellaneous troubles including umbilical hernia, umbilical infections, lumpy jaw, diphtheria, eczema, parasites, forage poisoning, lead poisoning, septicemia, retained placenta, difficult calving, and troubles of an undetermined nature.

The troubles and diseases encountered in the calves are listed in Table 15, while the troubles and diseases encountered in animals over 1 year of age are listed in Table 16.

TABLE 15.—*Morbid conditions encountered in calves*

Troubles encountered	Cases	Deaths	Troubles encountered	Cases	Deaths
Nutritional disturbances	132	24	Diphtheria	2	0
Lung trouble	82	26	Eczema	4	0
Udder troubles	2	0	Exposure to cold	1	1
Injuries and lameness	38	5	Anomalies	3	3
Umbilical hernia	4	1	Weak at birth	8	8
Umbilical infection	10	0	Undetermined	6	6

TABLE 16.—*Morbid conditions found in animals over 1 year old*

Conditions encountered	Animals	Cases	Deaths	Conditions encountered	Animals	Cases	Deaths
Nutritional disturbances	153	241	4	Eczema	5	5	0
Foreign bodies	17	17	17	Forage poisoning	1	1	0
Lung troubles	7	7	1	Lead poisoning	3	3	3
Udder troubles	76	81	0	Septicemia	6	6	6
Injuries and lameness	115	159	2	Retained placenta	54	64	0
Umbilical infection	1	1	0	Assistance to cows calving	30	32	0
Lumpy jaw	3	3	2	Undetermined	2	2	2

NUTRITIONAL DISTURBANCES

Digestive disturbances encountered in the mature animals include refusal to eat, overloading of the rumen and its refusal to work, intoxication from eating moldy or spoiled feed, lack of moisture in the digestive tract, serious bloat, impaction, constipation, diarrhea, and in calves twisting of the abomasum, and so-called white scours. Treatment varies with each case and is directed at the removal of the undesirable substance from the digestive tract and the elimination of the cause.

Three of the four deaths among the mature animals were from bloat and one from a severe case of gastroenteritis. Of the 24 calves that died, 5 died of varying degrees of gastritis while being used for a feeding experiment, between the ages of 19 to 59 days. Twisting of the abomasum was responsible for the death of 2 calves at the ages of 24 and 60 days, respectively. The other 17 calves died of gastroenteritis, at ages ranging from 6 to 193 days.

Seven cows have been affected with a disease or disturbance that has not been diagnosed. They walked stiffly, showed pain at the slightest touch, some of them were unable to get up for several days,

their backs were drawn up in a hump or bent sidewise and other joints of the body were partly flexed, but the appetite was not noticeably disturbed. Three calves similarly affected showed the same symptoms accompanied by mild rickets. The symptoms were noticed in the cows within a month after freshening and in calves between 1 and 2 months of age. All of these animals responded readily when calcium lactophosphate or calcium chloride was administered in small doses daily.

FOREIGN BODIES

The foreign bodies most frequently found in Beltsville animals were pieces of wire and nails. In 12 of the 17 cases the diaphragm had been pierced. In 3 cows wires were found in the liver. One cow died as the result of wire passing from the stomach through the abdominal wall. Another animal had swallowed a metal burr that ruptured the fourth compartment of the stomach.

LUNG TROUBLES

Lung troubles include congestion and inflammation of the lungs and their coverings. The cow that died of pneumonia had been affected intermittently from calfhood to maturity. It is thought that most of the calves became affected from exposure to cold drafts of air. Light, cleanliness, ventilation, and an even temperature have been found to be most efficient aids in the treatment of lung troubles. The age of the 26 calves that died of lung troubles ranged from 13 to 304 days.

UDDER TROUBLES

Twenty-three cows in the abortion-negative herd, 33 cows in the abortion-positive herd, and 2 calves, were affected with mammitis. Some of the cases of mammitis in older cows appeared near the end of long lactation periods, and the cause has not been ascertained. Other cases of mammitis in cows apparently were the result of bruises and poor milkers. Udders were injured most frequently when cows were in œstrum. Udder injuries in the two calves may be attributed to other calves sucking them. The most satisfactory treatment applied in cases of mammitis has been the hastening of elimination, frequent milking, and massage.

Cowpox has given practically no trouble in the Beltsville herds. It has been present in a very mild form in several barns but lasted only a short time.

INJURIES AND LAMENESS

Injuries included bruises and broken ribs from blows received by animals while fighting; bruises caused by running into fences and by striking the brisket on mangers and watering troughs; broken bones resulting from animals getting caught in partitions; foreign objects such as straw and splinters in the eyes; and puncture wounds made by forks and nails. Several calves were injured, some of them fatally, by being stepped on by their dams. Treatment to fit the conditions was given.

Injury to the lower jaw of a cow caused her death. A deposit of urine in the subcutaneous tissue and muscles throughout the lower part of the body, as a result of a rent in the urethra, was responsible for the death of a bull. The injury occurred during coitus. Injuries

such as broken vertebra in the back, crushed ribs, and bruised bodies were responsible for the deaths of five calves ranging in age from 3 to 337 days.

Most of the lamenesses were due to foot rot, stone bruises, and nail punctures. In the younger animals the so-called foot rot usually was located between the digits; and in the older, heavier animals the sole was more frequently affected. Three abortion-positive cows were affected with enlarged joints. Foot rot has been treated successfully by the use of formalin solution.

MISCELLANEOUS TROUBLES

Of the four cases of umbilical hernia, two were those of calves which were successfully treated by surgical interference, one was that of a grade bull calf which was disposed of without treatment, and one was that of a calf which died before it was 72 hours old.

Most of the umbilical infections in calves were found in one pen. Treatment with tincture of iodine has been successful. Thorough cleanliness has been an excellent preventive.

Treatment of lumpy jaw by the administration of potassium iodide was sufficiently successful to carry the animals affected through the experiments in which they were included.

Diphtheria in two calves was successfully treated by the discrete use of formalin solution and argyrol solution.

Eczemas were successfully treated by hastening elimination and the application of soothing ointments.

A case of apparent forage poisoning was successfully treated by dilution of the contents of the digestive tract and the administration of antitoxins. Recovery was slow, the animal taking six weeks to return to normal eating and drinking, and not gaining in flesh until five months later.

The eating of paint that had been spilled in a lot caused the death of three animals.

One calf died as a result of exposure to extreme cold when it was 316 days old.

An anomaly causing the death of three calves was the lack of a passage between the stomach and small intestines. These calves died on the second, ninth, and tenth days of life, respectively.

Septicemia having its source in the udder was responsible for the death of three cows. The source of the infection was not found in the other three cows that died of septicemia.

Removing the placenta by hand 48 hours after calving has been a satisfactory way of dealing with retained placenta in the Beltsville dairy herds.

Reasons for difficult births were abnormal presentation of the calf, lack of vigor in the dam, passages too small for a normal calf, and the calf being too large for a normal passage.

DISCUSSION AND SUMMARY

Records concerning fertility of cows and bulls, sterility, control of abortion disease by separating positive and negative animals, and the occurrence of other diseases in the animals at the United States Dairy Experiment Station at Beltsville, Md., are presented. Information is included on the comparative breeding efficiency and calving efficiency of abortion-negative and abortion-positive groups of animals.

The evidence presented shows that there is little difference in breeding efficiency between abortion-negative and abortion-positive animals when periods of four years are considered. The abortion-positive animals were somewhat more efficient when kept in a separate herd than when kept with the abortion-negative animals.

The percentage of heifers that conceived was as large as the percentage of cows that conceived, but more services were required for conception in heifers than were required in cows.

More services were required for conception in abortion-positive animals than in abortion-negative animals, both before and after separation of the two groups. The number of services for conception in abortion-positive animals after separation exceeded the number required before separation.

The least number of services required for conception was in the abortion-negative cows, and the greatest number was required by the abortion-positive heifers.

A study of the distribution of services shows that a little more than 40 per cent of the conceptions resulted from the first service, and a little more than 70 per cent of the conceptions resulted from the first three services.

A greater number of services were required for conceptions following abortions than were required for conceptions following normal calvings. This indicates that it takes longer for the genital organs to recuperate after an abortion than after a normal calving.

The number of mature cows that became sterile was larger than the number of immature cows.

More services were required for a conception in July, August, and September than in other months of the year.

Young bulls were more efficient than mature bulls when mated to fertile cows.

The percentage of live calves born in the abortion-negative group was lower after the separation of the groups than before, but higher that that in the abortion-positive group in either period. This decrease is probably due to the increase in number of calves born dead at the termination of first pregnancies and to the increase of abortions in old cows.

The abortion rate decreased in the abortion-positive group after separation from the regular herd, except when newly infected animals were added. There was no decrease in abortions during the 4-year period before separation. Abortions in the animals of the original abortion-positive group decreased rapidly after separation, and make up only 46.77 per cent of the total abortions in the abortion-positive herd.

In the abortion-positive females more abortions were found among first pregnancies than others. Fewer abortions were found among mature cows after separation of the groups than before.

Correct diagnoses are essential for the proper handling of sterility. Some of the morbid conditions of the genital organs that may be ascertained readily in the living animal are persistent corpora lutea, ovarian cysts, atresic follicles, and some inflammatory changes.

Data presented indicate that oestrum and successful breeding followed the removal of persistent corpora lutea in cows failing to come in heat.

Treatment of ovarian cysts was successful in mild cases, and unsuccessful in the majority of cases where nymphomaniac symptoms were present.

Forced exercise was beneficial in cases lacking muscular tone.

Data are presented showing the number of services before and after germinated or sprouted oats were fed to cows that were not conceiving but that had no indications of pathological conditions in the genital organs. Also, breeding data are given on heifers fed sprouted oats before being bred.

The number of females of breeding age in the abortion-negative herd, which includes the offspring from the positive herd, increased from 71 to 139 during the 4-year period May, 1926, to May, 1930.

The abortion-positive females decreased in number from 85 to 68 in the same period. This decrease came about through disposing of old, sterile, or unsound animals and also as a result of the fact that, since the offspring were transferred to the negative herd, there was no chance for increase in numbers except through the addition of newly infected animals from the negative herd.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

THE CITRUS BLACKFLY[1] IN ASIA, AND THE IMPORTATION OF ITS NATURAL ENEMIES INTO TROPICAL AMERICA

By CURTIS P. CLAUSEN, *Senior Entomologist*, and PAUL A. BERRY, *Junior Entomologist, Division of Fruit and Shade Tree Insects, Bureau of Entomology*[2]

CONTENTS

	Page		Page
Foreword (by C L. Marlatt)	1	Potential status of the blackfly in the United States	19
Introduction	3	Natural enemies of the blackfly	19
The citrus blackfly	4	Parasites in tropical Asia	20
Distribution	4	Predators in tropical Asia	36
Status as a citrus pest in the Far East	7	Native predators in Cuba, Panama, and Jamaica	45
Host plants	8	Fungous diseases	46
Life history and habits	10	Methods of rearing, shipment, and colonization	47
Mortality factors	11	Summary	56
Climatic conditions in the infested regions	13	Literature cited	58
Relation of meteorological conditions to blackfly development	16		
Comparison with Florida and California	17		

FOREWORD

The introduction and establishment of important Malayan parasitic and predacious enemies of the blackfly in the American Tropics, recorded in this bulletin, is one of the outstanding successes in this rapidly growing field. The effort was a cooperative one, supported by Cuba and the United States. The blackfly in Cuba has been for many years a very serious obstacle to the citrus industry and had in addition a fairly wide distribution elsewhere in the American Tropics. The interest of the United States was to reduce the risk of entry of this pest into the citrus areas of Florida or other of our subtropical areas, and also as provision for aid in future control

[1] *Aleurocanthus woglumi* Ashby.

[2] The authors wish to acknowledge the many courtesies and the valuable assistance rendered during the course of the foreign investigations by the officials of the Departments of Agriculture of the Federated Malay States and of the Dutch East Indies. J. M. McGough has assisted in the colonization work in Cuba since June, 1930, and D. W. Jones, of the Division of Cereal and Forage Insects, was present in an advisory capacity during the early work upon the imported parasites during April and May, 1930. James Zetek, in charge of the Bureau of Entomology laboratory at Balboa, Canal Zone, rendered valuable assistance in the preparations for the second trip to Malaya and was responsible for the colonization and establishment of *Eretmocerus serius* Silv. in Panama. S. C. Bruner, of the Estacion Experimental Agronomica in Cuba, and J. J. Bowman, of the United States Bureau of Plant Industry, made the citrus canker inspections of the final shipment. Determinations of the species dealt with in this bulletin are by the following specialists: Chalcidoid Hymenoptera by A. B. Gahan, Coccinellidae by E. A. Chapin, Lepidoptera by C. Heinrich, and Diptera by J. R. Malloch.

should this pest at any time succeed in establishing itself in the regions indicated. As to Cuba, the present indications are that the blackfly problem has been solved. The more important of the introduced parasites is now distributed practically throughout the citrus-growing areas of Cuba, and wherever a sufficient time has elapsed, a satisfactory commercial control of the blackfly has resulted. This parasite has also been distributed from Cuba to other points in the West Indies and Central America where the blackfly occurs. It seems desirable, therefore, both for the purpose of record and with the object of giving credit, to indicate the preliminary steps which led to the undertaking of this work. The persons directly concerned with its execution are the authors of this bulletin.

With the introduction and spread of the citrus blackfly in Cuba, the desirability was apparent of establishing there and at other points in the West Indies and Central America the controls of this new pest, parasitic or predacious, which might be found in its country of origin, and it was agreed that such effort should be made as soon as opportunity and funds made it possible. The finding by the Italian entomologist, F. Silvestri, of important parasites of the blackfly in Malaya, and his publications on this subject (1926–27) gave definite information of the existence of such natural controls. These papers, coming to the attention of J. F. Tristan, San Jose, Costa Rica, led him to make inquiry of Professor Silvestri of the possibility of the introduction of such parasites, and the latter in reply wrote him September 29, 1927, indicating that in his belief such introduction into the West Indies and Central America could be easily accomplished. Professor Tristan published Silvestri's letter in Costa Rica and presented the desirability of the importation to the agricultural society of that country but without action being taken. In furtherance of such importation, however, Professor Tristan transmitted March 5, 1928, a copy of Silvestri's letter to M. M. Marsh of the United Fruit Co., who in turn gave it to J. R. Johnston, director of the agricultural research department of that company. Doctor Johnston sent the letter to the Bureau of Entomology, asking for verification of Professor Silvestri's observations and suggesting the possibility of financial aid from governments and from individuals in interest, including his own company. Subsequent correspondence with Doctor Johnston brought out the fact that the United Fruit Co. was not in position to assume the full cost of this work. The bureau was unable to furnish funds to adequately finance the importation, but as a cooperative project the bureau agreed that it should take the lead and that at least it could furnish by transfer a thoroughly experienced specialist to make the necessary studies and undertake the importation of the parasites, if the travel and incidental costs could be cared for otherwise, and Doctor Johnston was so advised under date of April 3, 1928.

The interest of the Government of Cuba in the proposed importation of parasites of the blackfly was apparently initiated in June, 1928, by J. H. Montgomery, quarantine inspector of the State Plant Board of Florida, who was in Cuba and had a conference with the Secretary of Agriculture, Commerce, and Labor of Cuba, Eugenio Molinet, and with Ernesto Sanchez Estrada, Chief of the Bureau of Plant Sanitation. The idea of such importation was received

very favorably by these officers of the Cuban Government. Doctor Montgomery reported this conference to the State Plant Board of Florida at its July meeting of that year, and this body indicated that it felt that the undertaking should be handled through the Bureau of Entomology of the United States Department of Agriculture. The following August Doctor Montgomery was in Washington and reported his conference with the Cuban authorities to the Bureau of Entomology, and the proposed cooperation in importation of parasites of the blackfly was immediately taken up with the Cuban Government through the embassy in Washington. It was indicated through the embassy that Cuba, through lack of trained personnel for the technical features of the work, would be glad to have the United States Department of Agriculture undertake the parasite studies in foreign countries and the work of importation and also the handling and establishment if possible of the parasites in Cuba, and this arrangement was made a part of the final agreement. The original idea had been to include also importations of parasites of the white fly, the important citrus pest of Florida, and that Florida should contribute to the cost, and such contribution to the amount of $1,500 to $2,000 was indicated as a possibility in a letter from the plant commissioner, Wilmon Newell, of August 8, 1928. In the workout of the negotiations, however, with Cuba, through the agency of A. C. Baker of the Bureau of Entomology, it seemed wiser to confine the undertaking specifically to importations of parasites of the blackfly. A general memorandum of agreement was therefore drawn up in Cuba with the assistance of Doctor Baker and Doctor Montgomery, and these documents, dated November 5, were duly signed by Secretary Molinet for the Cuban Department of Agriculture, Commerce, and Labor, and later by Secretary Jardine for the United States Department of Agriculture. To carry out this project the Cuban Government made available $10,000 for the fiscal year 1929 to meet the costs of travel and expenses concerned in the parasite studies in Malaya and the collection and shipment of parasites to Cuba via the United States, and this support was continued into 1931. The contributions of the United States Department of Agriculture altogether practically duplicated this expenditure and covered, as already indicated, foreign studies, importation, establishment, and early distribution of the parasites in Cuba and elsewhere in Central America and the West Indies.

C. L. Marlatt, *Chief of Bureau.*

INTRODUCTION

The citrus blackfly, *Aleurocanthus woglumi* Ashby, has become in recent years a major pest of citrus in Cuba and various other islands of the West Indies, in the Bahamas, and in some sections of Central America. Since the first finding of the species in Jamaica in 1913 it has spread rapidly, and its eventual appearance in all of the tropical sections of the New World seems probable. Badly infested leaves wither and drop off as a result of injury caused through extraction of the cell sap by the insects in feeding. Such defoliation weakens the tree, interferes with its normal development and fruiting, and makes it unsightly.

In view of the importance of this pest and the possibility of its introduction into Florida and the Gulf States, the question of its control became urgent. The field of biological control was considered to present encouraging possibilities, particularly in view of the observations by Silvestri (*10*, *12*)[3] in the Far East. This ultimately led to the formulation of a cooperative project between the United States Department of Agriculture and the Department of Agriculture, Commerce, and Labor of Cuba for the importation of the natural enemies of the blackfly from tropical Asia into Cuba (fig. 1) and other infested sections of the West Indies and Central America.

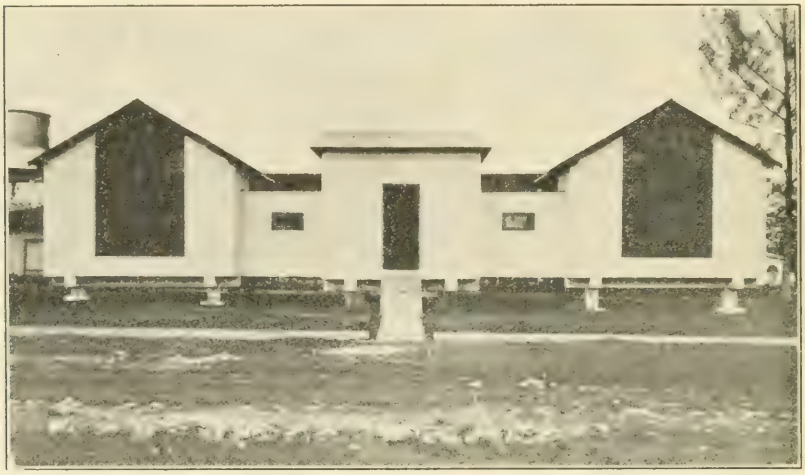

FIGURE 1.—The insectary at the Estacion Experimental Agronomica at Santiago de las Vegas, Cuba, where facilities were provided for the rearing and colonization work with the natural enemies of the citrus blackfly. (Photo by Cuban Agricultural Experiment Station)

In Cuba the colonization work has been in close cooperation with the Sanidad Vegetal, of which Ernesto Sanchez Estrada is chief. The foreign phase of the work was started by the senior writer in May, 1929. The necessary studies, with the later shipments of parasite material, covered the period from that date to August, 1931, and involved two trips to tropical Asia. The junior writer took charge of the rearing and colonization work in Cuba in January, 1930.

THE CITRUS BLACKFLY

DISTRIBUTION

The various sections of the Far East in which *Aleurocanthus woglumi* is now known to occur are shown in Figure 2. The earliest records of this species are from India, Ceylon, and the Philippine Islands. Silvestri (*10*, *12*) reports it at Singapore, Straits Settlements, in Indo-China, and in southern China. To this list may now be added Siam, Malaya, Java, Sumatra, and Burma. It may therefore be considered to be of general distribution throughout the tropi-

[3] Italic numbers in parentheses refer to Literature Cited, p. 58.

cal and subtropical regions of Asia below latitude 25° N. The distribution of this species in the East Indies, aside from Java and Sumatra, is not known, though its general occurrence in all other sections of tropical Asia would indicate its presence on all islands

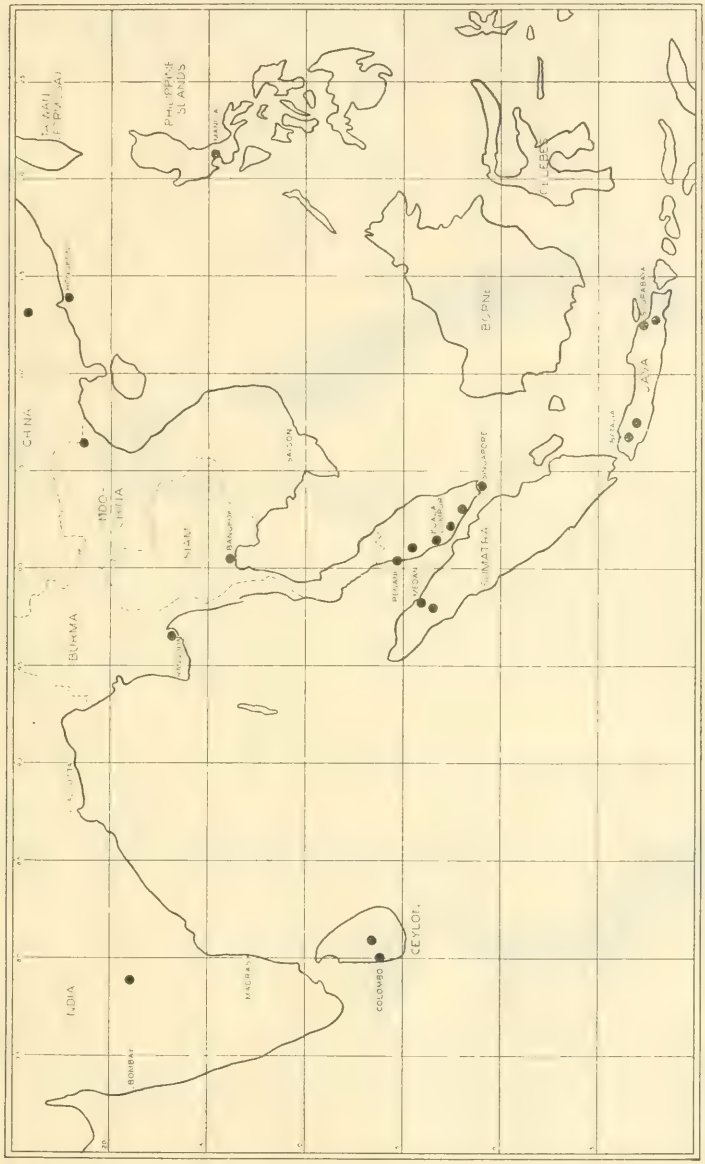

FIGURE 2.—Map of tropical Asia, showing by dots the present known distribution of the citrus blackfly in that region. Several localities in northwestern India are not shown

where citrus is produced. Its dispersion through the East is largely insured by the presence of Chinese settlements in all countries and islands in the equatorial region. Invariably the Chinese gardeners establish small nurseries in these communities, and citrus is always

included among the plants grown. Aside from the ordinary varieties used for fruit production, the dwarf trees are in much demand for ornamental purposes. These are brought from China or the older settlements in Malaya and serve as a ready means of insect introduction. The quarantine regulations now in effect in the Dutch

FIGURE 3.—Map of the West Indies and Central America, showing the present distribution of the citrus blackfly. Infested islands and countries are shown in black

East Indies have completely stopped the movement of citrus, except where certified as free from pests, but such measures are not as yet in effect in most of the other tropical countries.

In the New World (fig. 3) the species has spread from the original focus in Jamaica to Cuba, the Bahama Islands, Costa Rica, and Panama. The Cuban infestation is spreading rapidly, though the

entire island is not yet completely infested. Heavy infestations in these sections result in the almost complete loss of the crop. The extensive travel between the various islands and the general habit of the natives of carrying plants with them from place to place, combined with the lack of any plant-quarantine service in the smaller islands of the West Indies and in Central America, has permitted its rapid distribution. It is only a question of time until the species becomes established over the whole of the West Indies and Central America, following which its eventual entry into the United States will be difficult to prevent. The greater danger will probably come through the gradual advance of the pest up the Gulf coast through Mexico.

Several accounts have been published by the Cuban Experiment Station and the Sanidad Vegetal relating to the early observations upon the blackfly infestation in Cuba, its gradual spread through the island, and the measures taken in the attempt at eradication. Dietz and Zetek (*3*) present an extensive account of the species and its habits in Panama and the Canal Zone.

STATUS AS A CITRUS PEST IN THE FAR EAST

In the consideration of the insect pests attacking the various agricultural crops in foreign countries it is generally assumed that the status of the insect in its native habitat serves as a reliable criterion by which its potential status, if introduced into the United States or any other country, may be judged. The fallacy of this line of reasoning is strikingly evident in the case of the citrus blackfly and of many other species which have become established in the New World. It is becoming increasingly evident that all foreign plant-feeding insects, irrespective of their economic status in the country of origin, must be considered as potential major pests if established in a new environment, and this quite possibly upon host plants widely different from those already known.

The exact status of the various citrus pests in tropical Asia is at times difficult to determine, owing to the manner and extent to which the fruit is grown. In Malaya citrus is not grown at all extensively, and only an occasional commercial planting can be found. A few trees are usually present in practically every Chinese garden in the various cities and villages of the peninsula, and the insect population of these varies greatly. The lack of extensive plantings prevents the spread of any one species over a large area and its attainment of a permanent destructive status. Consequently, the dominant species is different in the various localities. The local nurseries usually serve as the focal points of insect dispersion.

There are several rather extensive citrus-producing sections in Java, the principal ones for orange being the hill section about 50 miles west of Sorabaya and the second about Garoet, both being at an elevation of 1,500 to 2,500 feet. Pummelo is grown quite extensively in the plains area between Batavia and Buitenzorg. In none of these sections was any species of Aleurocanthus found to be sufficiently abundant to cause commercial injury, the only heavily infested trees noted being occasional isolated ones grown in the gardens in the villages, though upon none of these did *A. woglumi* predom-

inate. This preference for garden rather than field trees is shown by *woglumi* in all localities in the Far East.

At Medan, Sumatra, there is a fair acreage of citrus surrounding the city, largely of pummelo and orange, and this is the only locality in Malaya or the Dutch East Indies in which the blackfly was found to be a constant and serious pest, though the species responsible was *A. spiniferus* rather than *woglumi*.

In all the countries of the Far East in which *Aleurocanthus woglumi* has been found, and in which it is presumably endemic, the species may be rated, at the most, as only an occasional minor pest.

It is of very general distribution in the groves of all infested regions, but is usually present in such small numbers as to escape observation. Occasional small groups of a few isolated trees, or a portion of a grove, may develop an infestation sufficient to cause marked injury to the trees, but such infestations are invariably quickly controlled by natural agencies, dominant among which are the internal parasites.

The small, isolated outbreaks mentioned above are not due to any temporary weakening in the controlling factors but to their virtual absence during the early periods of the infestation. The outbreaks observed have been, without exception, upon young trees 3 to 5 years old. Nursery stock is almost invariably infested. When this stock is transplanted to the field the clusters of mature blackfly larvae and pupae may be removed, but the eggs and young larvae escape detection. In this way a colony is started which is free from natural enemies, and consequently a high numerical status is attained within a short time. Sooner or later, however, the natural enemies reach this infestation from other trees in the neighborhood or from colonies of other species of Aleurocanthus present upon a variety of host plants, and control is then quickly effected. Numerical stability is never maintained at a high level.

HOST PLANTS

The great diversity of the host plants of *Aleurocanthus woglumi* in Panama, the Canal Zone, Jamaica, and Cuba led to the expectation that a similar condition would be found to prevail in its native habitat in tropical Asia. However, a striking distinction has been found to occur between the two regions in this respect. In those countries in which investigations were made by the senior writer, comprising the Philippine Islands, Siam, Malaya, Java, Sumatra, Burma, and Ceylon, citrus was found to be very nearly the sole host of the species. During two years of observations covering these countries, a total of not more than 20 clusters of larvae or pupae were found upon other plants. A few of these were upon *Vatica wallichii* Dyer and mango in the botanical garden at Singapore, upon *Nephelium* sp. at Bandoeng, Java, and a single cluster upon a coffee seedling in the nursery at Kuala Lumpur, Federated Malay States. In every instance observed the colony was very evidently due to a chance oviposition and showed no indications of permanency. It has been recorded by various authors as taken upon *Capparis peduncolosa* Wall., *C. roxburghii* D. C., *Kurrimia ceylanica* Arn., and *Salacia reticulata* Wight in Ceylon and upon *Morus* sp. in India.

In view of the host relationships of the blackfly in the Far East, as given above, the extreme rarity with which this insect is found upon mango casts some doubt upon the previously accepted manner of its introduction into Jamaica. Ashby (*1, p. 321*) considered it to have been brought into the island probably upon mango cuttings from India. In view of the habits of the insect it is extremely unlikely that it could have been carried upon cuttings at all, and more probably it came upon rooted plants instead, and of citrus rather than mango.

Dietz and Zetek (*3*), in their tabulation of the food plants of the blackfly in the New World, list more than 60 species, representing 30 families, from which it has been taken in Panama, the Canal Zone, Cuba, and Jamaica, and this number has since been greatly increased by Zetek for Panama and the Canal Zone. The above authors consider the various species of citrus, coffee (*Coffea arabica* Linn.), mango (*Mangifera indica* Linn.), and *Ardisia revoluta* H. B. K. as the preferred food plants upon which heavy infestations may normally develop. Their second class, upon which development to maturity occurs, but in small numbers, comprises the sapodilla (*Achras zapota* Linn.), Malabar plum, often called rose apple (*Caryophyllus jambos* (Linn.) Stokes), Malay apple (*Eugenia malaccensis* Linn.), mamoncillo, sometimes called Spanish lime (*Melicoccus bijugatus* Jacq.), oil nut palm (*Elaeis melanococca* Gaertn.), canistel, often called egg fruit (*Lucuma nervosa* A. DC.), sapote (*Calocarpum mammosum* (Linn.) Pierre), banana (*Musa sapientum* Linn.), guava (*Psidium guajava* Linn.), cashew (*Anacardium occidentale* Linn.), and sugar-apple (*Annona squamosa* Linn.). The remainder of the plants listed from Panama and the Canal Zone are those upon which the adult flies feed and may oviposit, but upon which they are unable to develop to maturity. While these may be listed as food plants, they can not be included in a true host list.

In his report on the blackfly in Jamaica, Gowdey (*5*) includes citrus, coffee, and mango in the first class and the following in the second: Soursop (*Annona muricata* Linn.), sugar-apple (*Annona squamosa* Linn.), guava (*Psidium guajava* Linn.), avocado (*Persea americana* Mill.), breadfruit (*Artocarpus incisa* Linn.), star-apple (*Chrysophyllum cainito* Linn.), grape (*Vitis* sp.), nightblooming cestrum (*Cestrum nocturnum* Linn.), lignum-vitae (*Guaiacum officinale* Linn.), mahiva (*Madhuca latifolia* (Roxb.) Macbride), and wampi (*Clausena lansium* (Lour.) Skeels (*wampi* Oliv.)).

The above classification of citrus with mango, coffee, and *Ardisia revoluta* as representing the preferred hosts, in that heavy infestations occur upon them, is quite correct, but the increase on citrus is so much more rapid, and the infestation so much heavier, that it should, alone, be rated as the preferred host.

The willingness of the female of *Aleurocanthus woglumi* to oviposit upon a great range of plants unsuited to the development of the earlier stages is in marked contrast to its habit in Malaya, where voluntary oviposition practically never occurs upon plants other than citrus, even though they may be suitable for development. Potted mango and coffee seedlings were repeatedly hung in heavily infested

citrus trees during the period of maximum abundance of adults, yet very seldom was an individual observed to feed upon the foliage, and not a single egg cluster was ever deposited.

LIFE HISTORY AND HABITS

In view of the climatic conditions which prevail in Malaya, it is to be expected that the developmental cycle will be of minimum duration and the number of generations produced each year will consequently be nearly the possible maximum. The two localities in which close observations have been made upon this species are Singapore (lat. 1° 20′ N.) and Kuala Lumpur (lat. 3° 11′ N.). Although they are separated by only about 150 miles, a noticeable difference in development of the insect in the two localities was observed. While Singapore has a mean maximum temperature several degrees lower than that of Kuala Lumpur, and its total rainfall is approximately equal though more evenly distributed through the year, yet five and one-half generations are produced each year at Singapore as compared with five at Kuala Lumpur. The periods during which the adults of six consecutive generations could be found in the field in the two localities are shown in Figure 4.

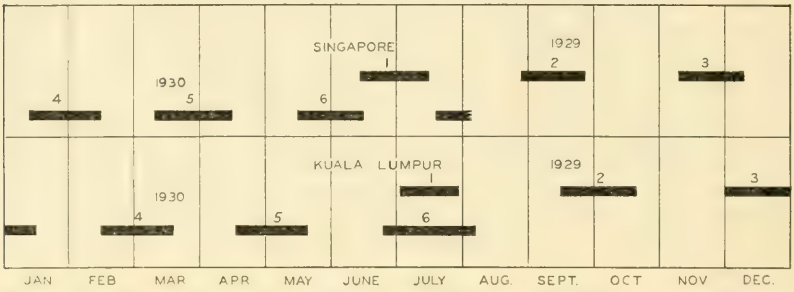

FIGURE 4. Chart showing the periods of adult emergence of six consecutive generations of the citrus blackfly at Singapore, Straits Settlements, and Kuala Lumpur, Federated Malay States

The acceleration in development occurring at Singapore as compared with Kuala Lumpur, which occurs in spite of the lower mean temperatures, is attributed to the greater uniformity in distribution of rainfall and to a more constant and higher humidity, these factors more than offsetting the higher temperatures. Occasional and irregular periods of dry weather, which tend to retard development, occur in both sections, though more frequently at Kuala Lumpur. Under optimum field conditions six generations can be produced each year, while under insectary conditions an additional one is possible.

A conspicuous feature of the life cycle of *Aleurocanthus woglumi* in Malaya is the distinctness of the generations. The adults of each are present on the trees for approximately one month, and in the intermediate periods not a single one can be found. This cycle, as represented in Figure 4, does not apply in time to all infestations in the two sections, but only to the particular trees under observation. Other trees situated a comparatively short distance away may not show an emergence synchronizing with that figured. To a large ex-

tent it is considered that this distinctness of generations is the result of relatively recent infestation, each one of these originating from a single focal point and, because of natural agencies, none persists for a sufficiently long period of time for the extremes of the generations to bring about an overlapping. Also, the period of development of the individuals from a single egg cluster is exceptionally uniform, as all adults emerge within a period of approximately one week.

While the complete life cycle covers a period of two months upon orchard trees under optimum conditions, yet upon nursery plants and in cages this period may be considerably shortened. Upon potted citrus seedlings kept outdoors but somewhat shaded, and with the foliage sprinkled each day, emergence of adults occurred within six weeks after oviposition. A similar shortening of the cycle was noted in the material reared in Wardian cages. The more succulent foliage upon which development took place, as compared with that of orchard trees, in conjunction with a higher and more constant humidity, was evidently responsible for this acceleration.

MORTALITY FACTORS

In the consideration of the various factors limiting the increase of *Aleurocanthus woglumi* in Malaya, these may be first listed as follows: (1) Adverse climatic conditions, resulting in failure of eggs to hatch, death of larval or pupal stages, and death of adult females without oviposition. (2) Natural enemies, which are internal parasites, predators, and fungous diseases.

With regard to climatic conditions it is shown, in the discussion under that heading, that a high mean humidity and a comparatively high and uniformly distributed rainfall are essential conditions for optimum development. During periods when optimum conditions do not prevail, a varying high mortality occurs in the different stages.

In the case of the egg stage a marked mortality is noticeable during periods of dry weather. This is in addition to the normal loss through infertility and also to the much greater mortality which at times occurs through presumed overcrowding upon favored leaves. The exact cause of this latter loss is not clearly understood, but leaves bearing large numbers of eggs closely massed together upon them will often show very few hatching, and at times none at all attain the intermediate larval stages.

The effect of reduced humidity and rainfall upon the intermediate stages is evidenced primarily by a high mortality in the first larval stage, and by a lesser mortality in the pupal stage through the drying out of the case, thus preventing the proper emergence of the adults. At such times many dead adults may be observed with the body partially extruded from the case.

The death of the females without oviposition is brought about by slashing rains, which drive them from the foliage and cause death directly, and by heavy winds extending over an extended period, which prevent feeding and oviposition and carry them away from host plants suitable for oviposition.

In Table 1 is given a compilation of the data secured through the examination of 100 representative clusters of *A. woglumi* taken from each of six consecutive generations at Singapore during 1929–30.

This table shows the average number of eggs per cluster and the mortality through natural agencies in the early stage and through parasite attack in the late larval and pupal stages.

TABLE 1.—*Data relating to survival, mortality, and parasitism of the citrus blackfly as observed at Singapore, 1929–30*

Generation	Egg spirals counted	Average of eggs per spiral	Average attaining late larval or pupal stage	Early-stage mortality	Average of larvae and pupae parasitized	Larvae and pupae parasitized
	Number	*Number*	*Number*	*Per cent*	*Number*	*Per cent*
First	100	47.35	22.86	51.72	13.23	57.87
Second	100	48.01	22.48	53.18	12.14	54.00
Third	100	41.68	17.52	55.57	9.71	55.42
Fourth	100	41.33	16.15	60.92	10.82	67.00
Fifth	100	44.33	20.64	53.44	12.50	61.17
Sixth	100	37.59	18.82	49.99	11.22	59.62
Average	100	43.38	19.74	54.14	11.60	59.18

In connection with the determination of the effects of the various mortality factors upon different stages of the fly, the count is given of the number of eggs in each of the 100 representative spirals of the six consecutive generations. It was found that the general average for the entire series was 43.38 eggs. This number is considerably in excess of the 32.19 given by Dietz and Zetek (*3*) for the same species at Panama. The proportion of eggs which failed to hatch is unknown, but 45.2 per cent of the total number attained at least the final larval stage, at which point the effect of internal parasites became evident. This is an exceptionally high survival rate, particularly as the series includes the stages most susceptible to adverse conditions.

As is to be expected, in view of the uniformity of climatic conditions in this section, the early-stage mortality, comprising the egg and first two larval stages, was also quite uniform, ranging from 49.99 to 60.92 per cent and averaging 54.14 per cent.

The figures for attack by internal parasites are based upon the count of emergence holes in the later stages and thus represent successful parasitization. The actual mortality is somewhat higher than that given, because some of the hosts were killed by parasites that died without effecting emergence. Through the agency of internal parasites alone, mortality ranged from 54 to 67 per cent in the late larval and pupal stages, with an average of 59.18 per cent. With this high percentage of parasitization, superparasitism and multiple parasitism enter into the question, both to a considerable extent, but the general effect of these two factors upon the ultimate mortality effected upon the host has not been studied.

The effect of predators upon this species in Malaya is reduced to a minimum, as they occur only in small numbers, being almost entirely absent in the great majority of the infestations. Only a single species, *Cryptognatha* sp., has been noted to produce an appreciable effect, and this occurred upon only two trees.

Fungous diseases caused by organisms of the genera Aschersonia and Aegerita are distinctly minor factors in relation to the blackfly in Malaya. Only occasional diseased individuals of *A. woglumi* may

be found in the field, a condition in marked contrast to that of a related species, *A. citriperdus*, which in Malaya and the Dutch East Indies is completely controlled by fungous disease during the wetter periods of the season.

Of the various limiting factors which have been considered, only two are of major importance, the first being adverse climatic conditions causing mortality principally in the first larval and the pupal stages, and the second being the internal parasites. In Malaya the general effect of these two factors may be rated as approximately equal.

CLIMATIC CONDITIONS IN THE INFESTED REGIONS

In Figure 5 are shown the curves representing meteorological conditions in the three main regions infested by the citrus blackfly. From the point of view of the economic status of the pest, the conditions for Kuala Lumpur may be taken as representative of the Malayan region. Most of the other sections in which the blackfly occurs, notably the Philippine Islands, the Dutch East Indies, Burma, India, and Ceylon, though having relatively high temperatures throughout the year, have distinct rainy seasons, with the comparatively long dry season occurring during the winter period.

The records given for Kuala Lumpur are for the years 1927–1930, inclusive, and are based upon hourly readings. The earlier records for that station were based upon three readings per day, these being taken at 9 a. m., 3 p. m., and 9 p. m., respectively. Climatic conditions are so uniform in this region, however, that a 4-year average is adequate for comparative purposes. A check of these hourly records with records of the same period based upon only three readings daily shows the mean monthly temperature to be approximately 3° lower and the humidity 6 per cent higher in the hourly records.

The records for Habana, Cuba, are for 1899-1924, inclusive, for temperature, 1897–1922 for humidity, and 1900–1922 for rainfall. The Balboa Heights, Canal Zone, records are for the 20-year period 1909–1928, inclusive. At these two stations the monthly means are calculated on the basis of 2-hourly readings, which check quite closely with those taken each hour.

In total annual precipitation it is seen that Habana, with 43 inches per year, is much lower than Balboa Heights with 68.8 and Kuala Lumpur with 94.2, while both of the former stations present a very dry winter period of several months, during which the rainfall is very light. In contrast to this is the so-called dry period at Kuala Lumpur from June to August, inclusive, with a precipitation of 4 to 5 inches per month.

The temperature curves of Kuala Lumpur and Balboa Heights are distinctly tropical in form in that the monthly means vary little during the course of the year, that of the former ranging only from 77.7° F. in October to 79.8° in May, with an annual mean of 78.7°; while at the latter station it ranges from 77.4° in November to 80° in April, with the annual mean 78.6°. The recorded maxima of these two stations are 98° and 97°, respectively. In contrast to this the temperature curve of Habana is markedly subtropical, extending from 70.7° in January to 80.4° in August, with an annual mean of 75.8°. Maximum and minimum records are 96.4° and 50°, respectively.

In mean monthly humidity the range at Kuala Lumpur is from 81.25 per cent in March to 87.4 per cent in November, with an annual

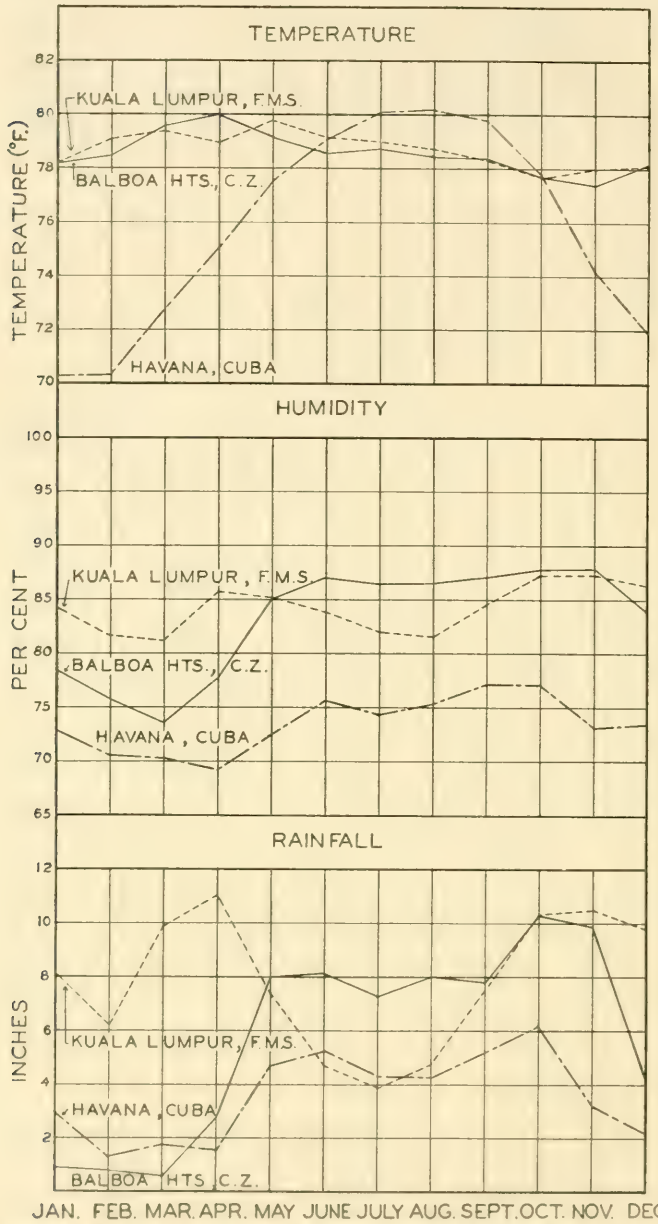

FIGURE 5.—Curves showing the mean monthly temperature, relative humidity, and rainfall for Kuala Lumpur, Federated Malay States, Balboa Heights, Canal Zone, and Habana, Cuba

mean of 84.3 per cent. At Balboa Heights the percentage ranges from 73.6 in March to 87.9 in November, while the limits for Habana

are 69.3 in April and 77.2 in September, the annual means of the two stations being 83.1 and 73.5 per cent, respectively.

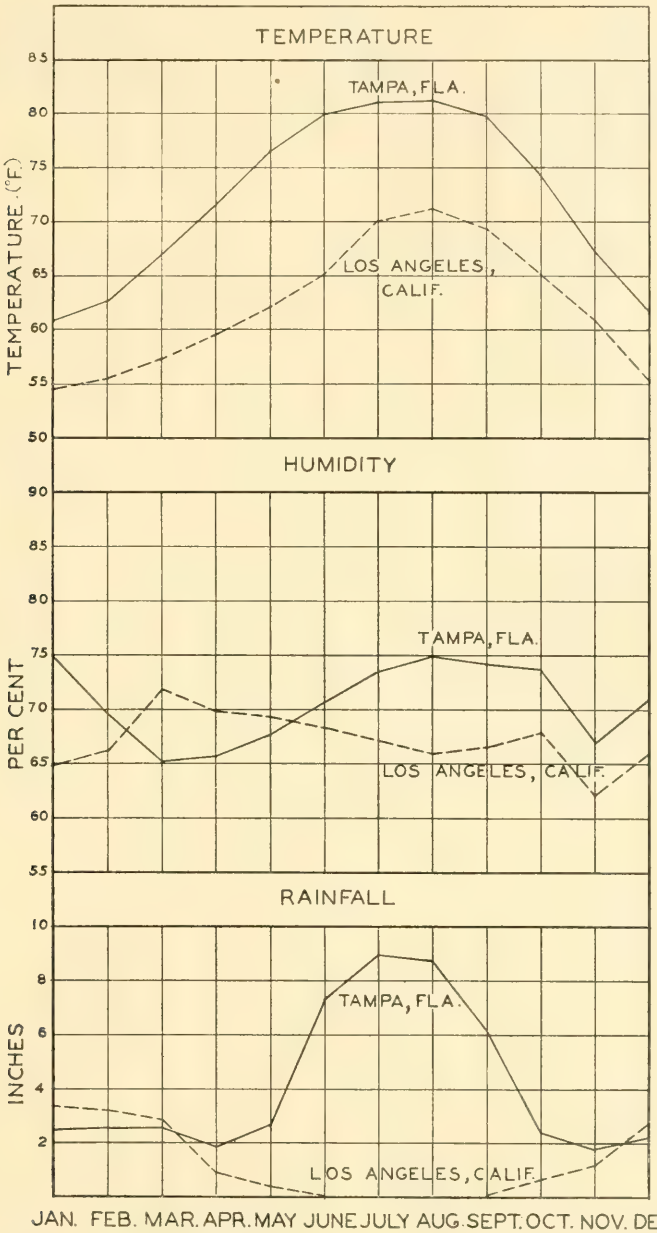

FIGURE 6.—Curves showing the mean monthly temperature, relative humidity, and rainfall for Tampa, Fla., and Los Angeles, Calif.

From the data presented it is seen that the climatic conditions at Kuala Lumpur and Balboa Heights present an exceptional similarity

in temperature and humidity, the differences in the annual means being only 0.1° and 1.2 per cent, respectively. It must be borne in mind, however, that Balboa Heights is not representative of the entire isthmian region. In Central America in general the Pacific side is relatively dry as compared with the Atlantic side. Thus Balboa Heights has only 54 per cent of the rainfall recorded at Colon, at the Atlantic end of the canal, with the mean annual temperature 1.2° lower and the humidity 0.2 per cent lower.

RELATION OF METEOROLOGICAL CONDITIONS TO BLACKFLY DEVELOPMENT

A comparison of the status of the blackfly in the various infested regions, in connection with the meteorological conditions prevailing there, gives a basis for the evaluation of the various factors in their relation to development and numerical increase.

From the data previously presented it is quite evident that such small variations in temperature as may occur in typical tropical regions, such as Malaya and Panama, can have no appreciable effect upon the development of the fly. In Cuba, however, the considerably lower winter temperatures undoubtedly retard development to a marked degree, but their further bearing upon the problem is difficult of determination because this season coincides with the period of minimum humidity and rainfall, which themselves have a retarding effect, aside from the actual mortality effected. This point may be illustrated by the annual cycle of the fly at Kuala Lumpur and Singapore. The former station has a mean monthly temperature several degrees higher than Singapore, but with the humidity lower and the rainfall less uniform. That the temperature factor is of secondary importance is shown by the development of five and one-half generations per year at Singapore as compared with five at Kuala Lumpur.

The two dominant factors, aside from natural enemies, which determine the status of *Aleurocanthus woglumi* as a pest are those of humidity and rainfall. The periods of heavy rainfall in the Tropics are accompanied by high mean humidities, while relatively high humidities may prevail without rainfall. A high humidity alone is not sufficient to insure a numerical increase in the blackfly population, in fact a marked decrease may take place. This is illustrated by the condition which existed at Kuala Lumpur during July, 1930. The mean temperature for the month was 79.3° F., or only a fraction of 1° from normal, the humidity was 82.1 per cent, or only 2.2 per cent below the annual mean, and the rainfall total was less than one-half inch. Under these conditions an exceedingly high mortality occurred in the egg and first larval stages. Likewise at Panama, with the mean monthly temperature ranging from 78.5° to 80° during the period of January to March, inclusive, the humidity from 73.6 to 78.5 per cent, and the rainfall from 0.6 to 0.9 inch per month, there is a striking decrease in the blackfly population. This comparison may be extended to Cuba, where a less pronounced, though very noticeable decrease takes place from November to April, inclusive, during which period the mean monthly temperature ranges from 70.7° to 75.1°, the humidity from

69.3 to 73.2 per cent, and the average monthly rainfall from 1.33 to 3.20 inches. Here, with a lower temperature and a lower humidity, but with a somewhat higher rainfall, the mortality is much less than in Panama.

It is thus seen that a high mortality occurred at Kuala Lumpur in July, 1930, even with the humidity figure 5 to 8 per cent higher than that prevailing in Cuba during June to October, the period of maximum development and increase, but the former locality having a much lower rainfall. Also, the mean monthly humidity in Cuba during these months is very nearly the same as in Panama during January to April, inclusive, yet in the former locality the fly is increasing rapidly and in the latter a marked decrease is taking place.

The analysis of the meteorological data presented reveals that, in tropical and subtropical regions, variations in temperature are of little consequence as bearing upon the development and numerical increase of the blackfly, and that a high humidity, accompanied by relatively heavy rainfall, is essential for optimum development. With a high humidity prevailing, the development and increase vary with the rainfall. The relatively heavier infestation of the fly in Panama as compared with that in Cuba is in accord with these conclusions. On this basis the Malayan conditions are even more favorable for optimum development than those of Panama, and the fly should consequently assume a destructive status. That it does not do so, but instead is of no consequence as a pest, is attributed to the effectiveness of the natural enemies present. Occasional isolated instances have been seen, representing single or small groups of young trees, upon which the blackfly has become established, and originally without its parasites, which have shown it to be able to increase from a very small number to a heavy infestation in three generations. The later permanent decline of these infestations to a position of no economic importance in each case has been due to parasite attack, as contrasted with an occasional temporary decline due to irregular periods of adverse climatic conditions.

COMPARISON WITH FLORIDA AND CALIFORNIA

In view of the possibility of the eventual entry of *A. woglumi* into the United States, a comparison of the meteorological conditions in the infested regions with those in Florida and California gives a basis for the estimation of the potentialities of the species with regard to its status as a citrus pest in these States.

In this comparison Tampa, Fla., and Los Angeles, Calif., have been chosen as representative of the citrus-producing sections of the two States, largely because more detailed data are available than for other points which might be considered somewhat more representative.

The conditions at Los Angeles are intermediate between those of the coastal sections and inland valleys, though in all sections the general conditions are very similar. The summer temperatures are relatively high, the humidity is low, and there is practically no rainfall. The total annual precipitation is low and occurs very largely during the months of December to March, inclusive.

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The curves showing mean monthly temperature, relative humidity, and rainfall for Tampa and Los Angeles are shown in Figure 6. Those of temperature are based upon records for 66 and 42 years, respectively, those of humidity for 4 and 5 years, respectively, and those of rainfall for 80 and 42 years, respectively. The humidity curve for Tampa is based upon bihourly readings, while that for Los Angeles represents only five readings daily, these being taken at 4 and 8 a. m., 12 noon, and 4 and 8 p. m. The mean is therefore probably slightly lower than would be shown by bihourly readings.

In mean monthly temperature the range at Tampa is from 60.8° F. in January to 81.2° in August, with minimum and maximum records of 19° and 98°, respectively. The mean summer temperatures are thus approximately the same as at Habana, while the mean winter temperature is approximately 10° lower. At Los Angeles the range extends from 54.5° in January to 71.1° in August, with minimum and maximum records of 28° and 109°, respectively. The mean monthly temperatures during the summer at Los Angeles are considerably lower than those in any of the other sections under consideration, though the maximum summer temperatures are considerably higher.

The mean monthly humidity at Tampa ranges from 65.2 per cent in March to 74.9 per cent in January and August, being thus about 4 per cent below that of Habana. At Los Angeles the monthly mean ranges from 62.2 to 71.8 per cent, or 7 per cent below the Habana figures.

In total annual precipitation Florida in general presents conditions quite similar to those of Habana, having an average annual rainfall of 50.19 inches, with the greater proportion falling during the months of June to September, inclusive, and with a maximum of 9.02 inches in July. From October to May the rainfall is relatively light, varying from 1.82 to 2.72 inches per month. In contrast, the Los Angeles records show an average annual rainfall of only 15.62 inches, largely occurring during December to March, inclusive. The maximum monthly precipitation is 3.34 inches in January, while the minimum is 0.01 inch in July.

A summarized tabulation is given herewith (Table 2) of the minimum and maximum monthly means and annual means of temperature and humidity and the minimum and maximum monthly and annual rainfall averages for the five localities under discussion.

TABLE 2.—*Summary of data relating to temperature, relative humidity, and rainfall in five localities*

Locality	Temperature				Relative humidity			Rainfall		
	Absolute maximum	Maximum monthly mean	Minimum monthly mean	Annual mean	Maximum monthly mean	Minimum monthly mean	Annual mean	Maximum monthly mean	Minimum monthly mean	Annual mean
	° F.	° F.	° F.	° F.	Per ct.	Per ct.	Per ct.	Inches	Inches	Inches
Kuala Lumpur, Federated Malay States	98.0	79.8	77.7	78.7	87.4	81.2	84.3	11.03	3.91	94.2
Balboa Heights, Canal Zone	97.0	80.0	78.2	78.6	87.9	73.6	83.1	10.3	.6	68.8
Habana, Cuba	96.0	82.2	70.7	75.9	77.2	69.3	73.5	6.21	1.33	43.0
Tampa, Fla	98.0	81.2	60.8	72.0	74.9	65.2	70.4	9.02	1.82	50.19
Los Angeles, Calif	109.0	71.1	54.5	62.3	71.8	62.2	67.7	3.34	.01	15.62

POTENTIAL STATUS OF THE BLACKFLY IN THE UNITED STATES

In comparison with the records for Habana, a locality in which the blackfly is a major pest, it is seen that in Florida the total amount and distribution of the rainfall and the range of the humidity are quite similar. Consequently, if *A. woglumi* should become established in Florida, its status may be expected to be approximately the same as in Cuba, but with a more pronounced period of delayed development during the winter due to the lower prevailing temperatures.

In view of the fact that the blackfly requires both a relatively high humidity and considerable rainfall during its period of development, both of which factors are conspicuously lacking in all of the citrus-growing districts of California, it is felt with a considerable degree of certainty that this insect, should it become established in that State, would have difficulty in maintaining itself and presents no possibility of increase to the status of a pest.

NATURAL ENEMIES OF THE CITRUS BLACKFLY

The first observations upon the natural enemies of *Aleurocanthus woglumi* in tropical Asia were made by Silvestri in 1924–25, during the course of his travels through that part of the world in the search for natural enemies of various other citrus insects for importation into California. His reports (*10*, *12*) on the parasites reared from Aleyrodidae upon citrus contain the descriptions and figures of four species found to attack *woglumi*, with an additional species since found to be a secondary parasite. Short biological notes are given regarding several of these species.

The complete list of natural enemies observed by the senior writer in the course of these investigations is as follows:

The internal parasites:

Hymenoptera (Eulophidae)—
- *Encarsia mercti* Silv.
- *Erctomocerus serius* Silv.
- *Prospaltella divergens* Silv.
- *Prospaltella smithi* Silv.
- *Prospaltella* sp.

The predators:

Coleoptera (Nitidulidae)—
- *Cybocephalus* sp.

Coleoptera (Coccinellidae)—
- *Cryptognatha* sp.
- *Scymnus smithianus* Silv.
- *Scymnus* sp. near *pallidicollis* Muls.
- *Scymnus* sp.

Lepidoptera (Pyralidae)—
- *Cryptoblabes gnidiella* Mill.

Diptera (Drosophilidae)—
- *Acletoxenus indica* Malloch.
- *Acletoxenus* sp.

Neuroptera (Chrysopidae)—
- *Chrysopa* sp.

PARASITES IN TROPICAL ASIA

GENERAL PARASITIZATION RECORDS

The fact that the blackfly, in any given locality in its native habitat, is attacked by several species of internal parasites, rather than by one alone, has made it difficult to determine with any degree of exactitude the relative effectiveness of the different species. This is largely due to a difference in the time of emergence from the host pupa, as collections will yield a varying proportion of one species or another, depending upon the time of collection of the host material. In any case, the relative numbers vary considerably in infestations in the same general locality. The aggregate mortality effected, however, is fairly constant throughout Malaya and the Dutch East Indies.

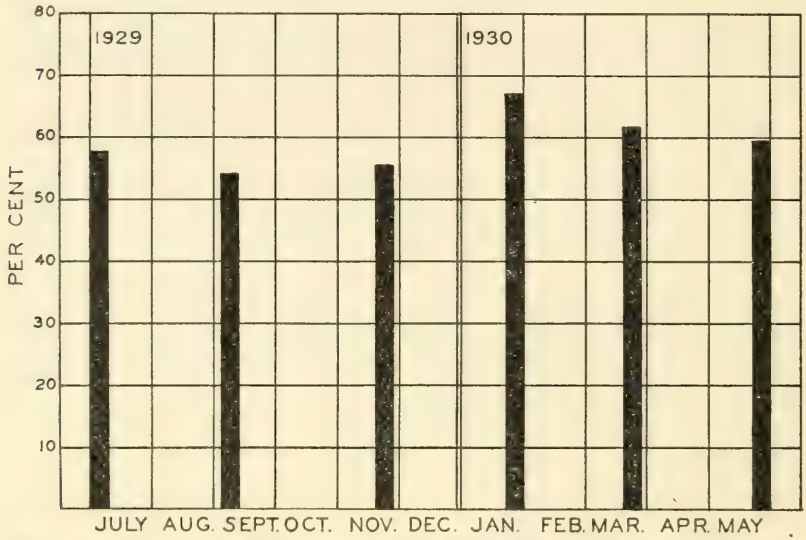

FIGURE 7.—The percentage of parasitization in six consecutive generations of the citrus blackfly at Singapore

The greatest uniformity in field parasitization in the various countries where *A. woglumi* was studied was revealed in Malaya. Examinations for the determination of the total mortality effected by the internal parasites were made for six consecutive generations at Singapore, and the proportion destroyed through these agencies is shown in Figure 7, the range in percentage being from 54 to 67. The higher rates of parasitization appear during the first half of the year, and coincide in time with a slight upward trend in the numerical status of the host, this being a normal seasonal development.

The figures for parasitization of each generation are based upon the collection of 100 representative clusters shortly after the time of emergence of the host adults, each cluster being the product of a single egg spiral, and all taken in the same general locality. These collections of clusters comprised totals ranging from 1,615 to 2,286 individuals which had attained the mature larval or pupal

stage and were thus sufficiently advanced to be subject to successful attack by parasites. The figures given represent the percentages of these showing parasite emergence holes.

The percentages shown for the successive generations are believed to represent less than the total actual mortality occurring in the field, as a considerable proportion of the individuals of the secondary parasite failed to emerge from the collected material. This was established by the dissection of mature larvae and pupae which had failed to yield either host or parasite adults; and in a considerable proportion, the remains of parasite larvae or pupae were found.

General observations made in various localities in Malaya between Singapore and Penang have revealed that the effectiveness of the internal parasites throughout this general region closely approximates that found at Singapore. The markedly dominant species at Singapore was *Prospaltella divergens*, and at Kuala Lumpur it was *Eretmocerus serius*. *Prospaltella smithi* was dominant to a lesser degree in several other localities. Instances of effective field control have been seen in which each of these has played the dominant rôle. The disparity in numbers between the species was usually so great as to demonstrate the ability of the single species to control the host.

HYMENOPTERA

Encarsia merceti Silvestri

This species is fairly common, though never abundant, as a parasite of *Aleurocanthus woglumi* in Malaya and the Dutch East Indies, in which sections it is always dominated by Eretmocerus or Prospaltella. Oviposition occurs in the advanced larval stages of the host, and the adults emerge from the host pupae.

Eretmocerus serius Silvestri

GENERAL

This species was originally described by Silvestri (*10*) from specimens reared from pupae of *Aleurocanthus woglumi* collected at Singapore. The senior writer's observations have shown it to occur throughout Malaya and the Dutch East Indies and also in Siam, Burma, and Ceylon. Its greatest abundance is attained upon *A. woglumi* in Malaya, though it has been frequently reared from *A. citriperdus* Q. and B. and, to a lesser extent, from *A. spiniferus* Q. and other native species of the genus. In this region it ranks with *Prospaltella divergens* as one of the most important of the natural enemies of the blackfly.

A most striking illustration of the effectiveness of this species in the control of the blackfly was provided in a small grove near Kuala Lumpur during the early part of 1930. In this grove of young orange and pummelo trees several were very heavily infested and about a dozen moderately so. This was the only infestation of any importance known at the time, and consequently the adult flies were collected in as large numbers as possible for use in infesting the mango seedlings utilized as host plants for the first parasite shipment. These collections of adults were made throughout the period of emergence, extending from the middle of December to the middle

of January. In spite of the large proportion of adult flies taken from these trees there still occurred a very heavy oviposition upon the older foliage, amply sufficient to maintain or even increase the infestation. In view of this it was anticipated that the following generation would be sufficiently large numerically to provide adults for the preparation of an additional shipment.

As oviposition and hatching of the blackfly progressed the emergence of Eretmocerus took place, and within a short time the foliage was literally alive with the parasites. As many as 200 of these adults were noted at one time upon a single leaf. Realizing that this condition foretold the destruction of a large portion of the blackfly population, the trees were sprayed with a solution of sugar containing an arsenic compound, to reduce their numbers. This was effective against those already on the foliage, but additional parasites were emerging from day to day and the females apparently were able to effect a considerable oviposition before dying. The following brood of blackfly adults, which appeared in late February and March, was exceedingly small as compared with the preceding one. This reduction was very largely due to parasite attack, though aided by a period of relatively dry weather. That the latter was the minor factor was demonstrated by several other small infestations in the same locality, in which the blackfly population at that time showed a numerical increase. An examination of the same grove in the following July revealed the blackfly at the point of virtual extinction, as extensive search yielded only an occasional cluster, and not more than one was found upon any single tree. Both *Prospaltella divergens* and *P. smithi* were present in this infestation, though in very small numbers as compared with Eretmocerus.

COLONIZATION IN CUBA

The first shipment of Eretmocerus from Malaya was made in March, 1930, and arrived in Cuba late in April. From this consignment 42 females and 19 males were secured for rearing purposes. A few of these were liberated directly in infested groves, though the greater number were retained for insectary rearing. Reproduction in the cages took place quite readily, though the first insectary generation yielded only 62 females and 75 males and the second 670 females and 275 males. From this point onward the increase in numbers was very rapid, and sufficient quantities were available for extensive field colonization.

It was soon found that the rather laborious rearing of this parasite in the insectary in sufficient numbers for the colonization work planned was quite unnecessary, as field-collected material could be secured in much larger numbers and with considerably less expenditure of labor. In colonizing groves in the same general locality as that in which the parasite is collected, the adults were captured in tubes and then immediately released directly in the new groves or confined in bags upon suitable branches. Where the time of transportation to a new locality is so great as to render this means impracticable owing to mortality of the adults, the purpose is still readily accomplished by the shipment of infested leaves upon which the blackfly is largely in the pupal stage and the parasite consequently at the point of emergence. From such infested foliage,

kept in emergence cages or jars, or even placed directly in the groves, the adult Eretmocerus continue to emerge for a period of 10 to 15 days.

As previously mentioned in the discussion of the normal rate of parasitization of the blackfly in Malaya, the percentage of host mortality through parasite attack, in an infestation which maintains numerical stability, ranges from 50 to 67 per cent. In Cuba the percentage of mortality effected at the time when the host may be considered as fully controlled and the grove commercially clean ranges from 72 to 78 per cent. This is the result of attack by Eretmocerus alone, as compared with the series of three or four species in Malaya. The figures for five groves near Habana, all of which bore a heavy blackfly infestation, in which the earlier colonies were liberated and control effected prior to August 1, 1931, are as given in Table 3.

TABLE 3.—*Data relating to control of the citrus blackfly by Eretmocerus serius in five citrus groves near Habana, Cuba, 1931*

Grove	Trees	Date of colonization	Date of examination	Parasitization
	Number			*Per cent*
Santa Lucia	800	June–August, 1930	June 12, 1931	75.18
La Conchita	700	August, 1930	June 15, 1931	78.35
Cemetery	800	June–August, 1930	June 18, 1931	77.43
San Antonio	700	July–August, 1930	July 29, 1931	78.16
Rincon	900	June–August, 1930	July 30, 1931	71.85

Six additional groves were classed as commercially clean during August and early September.

In Santa Lucia grove, in which the first liberations were made in late June and in July, 1930, the control was quite complete on the date of examination. There was, however, a renewed outbreak of the blackfly in a portion of the grove in the generation developing in June and July, 1931. The parasitization of this generation, as determined by examination on July 17, revealed that the rate of parasite attack had dropped from 75.2 to 59.4 per cent. Even this, however, was sufficient to check the outbreak, and the following generation was numerically much smaller. This development occurred at the season providing optimum conditions for host increase, and in which a very rapid intensification of infestation normally occurs.

In these groves the parasite has fully demonstrated its ability effectively to control the blackfly under existing conditions. The late liberations are progressing satisfactorily and the percentage of attack is such as to give promise of control after an elapsed time approximately equal to that required for the groves above mentioned. Upon the basis of the development of the colonies thus far established the conclusion has been reached that commercial control, using a 5-acre grove as a unit, may be effected within 8 to 12 months through the liberation of a colony of 100 to 500 females at one or more points near the center of the grove. Larger plantings require the spacing of these colonies proportionately, to insure complete dispersion within a minimum period of time.

The liberation of greater numbers of parasites in the groves, in an effort to shorten the time elapsing before control is secured, does

not give results commensurate with the labor involved. Assuming that the actual rate of increase of the species is fifty times in each of the earlier generations, which is believed to be a conservative estimate for the initial generations, it would be necessary to liberate fifty times as many parasites in the original colony to effect a shortening of the required period by one month, representing one generation of the parasite.

Occasional instances have been noted in the field in which the percentage of parasite attack has been very high for several generations without exerting any appreciable check upon the blackfly. In these groves, however, the local conditions have been such as to induce an exceptional exuberance of development of the fly sufficient to withstand the loss through parasite attack and still provide a large surplus for increase. This was particularly well illustrated in Finca Mendieta at Hoyo Colorado, in which liberations were made in early August, 1930. Here the trees are interplanted with banana and mango, providing a certain amount of shade and giving an increased atmospheric humidity. The growth of the orange trees is much more luxurious than is normally the case. The parasite attack in this grove upon the generation maturing in early July, 1931, was found to be 66.6 per cent, and it was known to have been quite heavy for the two preceding generations also. In spite of this heavy mortality, which normally is sufficient to subjugate the host, the blackfly oviposition and development in the July-August generation was exceptionally heavy, yielding an infestation more extensive than that earlier in the season.

The above condition is not considered to have demonstrated any weakness in the control capabilities of Eretmocerus. No parasite can hope to cope with a host species so long as such an unusual development is taking place. During this time, however, the parasite population is being built up to a high numerical level and as soon as the host's upward swing begins to falter, owing to adverse climatic conditions, the full force of attack centers upon the weakened infestation. At this time the subjugation of the host is extremely rapid, and the numerical level to which it is forced is so low as to eliminate the possibility of a repetition of the conditions in succeeding generations.[4] Only six months of the year, covering approximately three generations, provide meterological conditions suitable for numerical increase of the blackfly even in infestations free from parasite or fungus attack.

Owing to the very active habits of the adults of Eretmocerus, the dispersion of the species may be rapid as compared with others of this group, though this dispersion is largely dependent upon the condition of the host infestation. Where an ample supply of blackfly larvae in the various stages is available for oviposition by the parasite, the latter remains largely in the locality of emergence. Observations upon the progress of Eretmocerus colonies in heavily infested groves show a general dispersion during the early periods of about five rows of trees for each generation. This is quite uniform in all directions and irrespective of the direction of the prevailing wind.

[4] This point is particularly well illustrated in the later developments in the above-mentioned grove, where commercial control was effected by Nov. 1, 1931.

When the host population has become much reduced the greater proportion of the adult parasites leave the trees upon which they developed and search for fresh host material. At this time the range of dispersion is much greater, and instances have been observed of spread to groves more than 1 mile distant, with no blackfly colonies in the intervening zone.

Figure 8 is a map of Cuba showing the points of colonization of Eretmocerus in the island to September 20, 1931. It is seen that the distribution of the parasite is now general in all Provinces, and these groves can be utilized as sources of supply for distribution to others in the same localities.

A total of 237 colonies had been liberated in the field up to the above date, of which 77 were in Habana Province, 67 in Oriente, and 59 in Camaguey.

The thorough distribution of the parasite to all infested groves is handicapped by the fact that there is no agency in the island through which information can be secured regarding the location of citrus plantings. The larger commercial groves are readily found, and practically all of these have been provided with parasite colonies. The smaller plantings, situated away from the main roads, are discovered mainly through the complaints of owners regarding insect damage. Extensive publicity, stressing the availability of parasites for blackfly control, will in time result in the reaching of these infestations and the consequent more general dispersion of the parasite. A considerable period of time will elapse, however, before this work can be considered complete.

LIFE HISTORY AND HABITS

Under normal field conditions in Malaya, where the host insect occurs in very clearly defined generations, with the adults present for a period of about one month rather than continuously, the Eretmocerus adults appear in greatest numbers during the latter part of the host emergence period. By this time a considerable portion of the early host eggs have already hatched and many of the first-stage larvae which are abundant on the foliage are ready to transform to the second stage. Oviposition by the parasite is in any stage from the first larval to the pupal, though preferably in the second larval stage, and the complete cycle covers approximately four weeks. Thus, the individuals which attacked the host material first available emerge when the latter portion of the host brood is still in the larval stage; consequently the parasite is able to develop two generations to each one of the host. This habit is very evidently markedly advantageous from the point of view of biological control, as it permits of the attainment of a high numerical level in a very short period and assures that no females shall die without oviposition through lack of suitable hosts at the time of emergence. In this respect Eretmocerus is definitely superior in adaptation to the other parasite species which have been studied, being entirely independent of any variation in the host cycle. In contrast to this, Prospaltella and Encarsia have only a single generation to each one of the host and are more restricted in their choice of the stage of the latter which they are able to attack successfully.

FIGURE 8.—Map of Cuba showing colonization centers of *Eretmocerus serius* in the various Provinces

In Cuba it has been found that development from egg to adult covers a period of 23 to 40 days under optimum summer conditions. This difference in time of development is due to the varying length of time which the early larval stages of the parasite must pass beneath the host in a semiresting condition. Where mature larvae or pupae are attacked this period is reduced to a minimum (23 to 30 days) whereas the longer period (30 to 40 days) is required in the case of those hosts which are attacked in their earlier stages. The developmental cycle of the male is normally about two days shorter than that of the female.

Under the seasonal conditions prevailing in Cuba, Eretmocerus breeds continuously throughout the year, though development is considerably retarded during the winter months. The numerical ratio in relation to the host increases during this time, however, owing to the decline of the latter through adverse climatic conditions.

Oviposition may take place in any stage from the first larval to the pupal, and maturity is attained from all of these stages. The great majority of eggs, however, are placed beneath second-stage larvae, and the third larval and pupal stages are attacked largely by the females of the first brood of parasite adults.

In ovipositing, the female approaches the host from the side and examines it momentarily with the antennae. She then reverses her position and thrusts the ovipositor into the mid-lateral region of the body at a downward angle. Both the dorsal and ventral body walls are pierced by the ovipositor, and the egg is placed on the leaf surface beneath the host, almost invariably in the area near the line dividing the thorax and abdomen. The entire process of oviposition covers less than one minute.

The manner of oviposition is very unusual in an aleyrodid parasite, as all of those which have been studied heretofore have been of true internal habit. Repeated dissections of host larvae in which oviposition had been seen to occur failed to reveal eggs within the body, and the fact that they remain attached to the leaf when the larva is removed prevented detection even by external examination. Occasionally an egg may adhere to the ventral surface of the host rather than to the leaf, and to this fact was due the eventual discovery of the true habit of the species.

The egg (fig. 9, B) when laid is 0.08 mm in length and 0.055 mm in maximum width, with a small protuberance at the anterior end and a broadened one at the posterior end. The shape is irregular, as shown in the figure. At first it is quite translucent, but later the chorion assumes a distinct amber or brownish color. At hatching the chorion splits across the front and about three-fourths the length on each side.

The primary larva (fig. 9, C) is 0.08 mm in length and not of the usual distinctly segmented form, but instead is pear-shaped or nearly globular, and with no apparent segmentation. The broad posterior or basal portion of the body retains connection with the eggshell and is partly enveloped by it. The larva is thus anchored to the leaf by the shell and the extension of the body upward brings the head and mouth parts into contact with the ventral surface of the host body, thus permitting a certain amount of feeding.

The second larval stage measures 0.14–0.15 mm in length and is similar in general form to the first, though with several constrictions visible which divide the body into three or four "segments." The connection with the eggshell is retained, while the first cast skin envelops the caudal portions of the body. No movement occurs in this or the preceding stage. Feeding continues externally, as before, though further development is delayed pending penetration of the host.

The period of time following the hatching of the egg, during which the parasite larva feeds externally, is dependent upon the stage of development of the host at the time of oviposition. While a certain amount of feeding takes place during these first two stages,

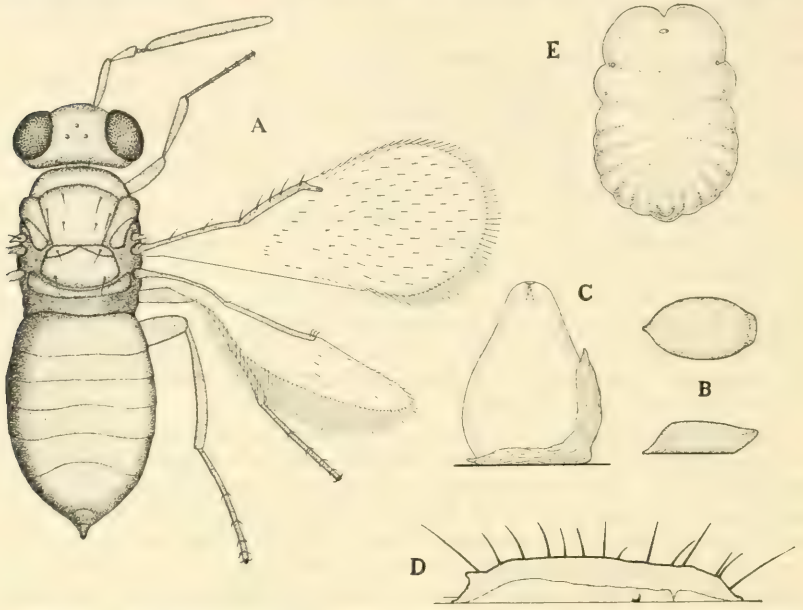

FIGURE 9.—*Eretmoceras serius:* A, Adult female, × 40; B, dorsal and lateral views of the egg, × 200; C, first-stage larva, × 230; D, diagrammatic longitudinal section of third-stage Aleurocanthus larva, showing the second-stage parasite larva beneath the body, × 35; E, dorsal view of fourth-stage larva, × 60

as a whole this period of external existence may be considered a waiting period, and the second molt is delayed until after penetration of the body. Irrespective of the stage of the host at the time of oviposition, the entry of the parasite larva does not take place until after the transformation of the host to the pupal stage, following which development is rapid.

At the time of penetration of the host a very distinct hole, 0.06–0.07 mm in diameter, is left in the ventral integument. The parasite larva apparently molts immediately after entry, and the cast skins, often with the eggshell as well, remain to seal the aperture. This point of entry is plainly evident externally and is surrounded by a brownish area which, in contrast to the normal black coloration, provides a ready means of distinguishing parasitized individuals. This entry is effected very shortly after the pupal stage is

attained, and the development of the pupa is almost immediately arrested. No instance has been observed of a parasitized individual developing sufficiently to make the body divisions or appendages distinguishable.

In view of the fact that the first and second stage larvae remain attached to the leaf through possibly several molts by the host, the habits of the latter at these times are of importance to the parasite. The successive molts are effected by a splitting of the anterior latero-ventral margin, this break extending to the posterior margin of the thorax. Immediately after emergence from the old skin a characteristic rotation of the body upon its axis occurs, this movement extending to a change, up to 180°, in position. At this time there is some chance of the minute parasite larva being left beyond the body as it settles, this of course being more possible in the first molt, when the host body is relatively small. However, the parasite egg is laid beneath the thoracic region, and the eventual penetration is also usually effected in this area, consequently it would appear that the center of rotation of the host is at that point.

The molt to the third larval stage occurs very shortly after entrance into the host body. In the great majority of cases this occurs in the thoracic region. The larva at this time is 0.3 mm in length and quite different in form from the two preceding stages, being almost globular, markedly weevillike, and with the segmentation distinct.

The larva is attached quite securely to the ventral derm of the host at the point of entry, but the manner in which this is accomplished has not been learned. The body lies embedded in the mass of tracheal branches present in this region of the host; but so far as can be determined, the constant position mentioned has no relation to respiratory activities.

The final larval stage (fig. 9, E) is 0.5 mm in length and very robust in form, though somewhat more elongate than the preceding stages, and distinctly segmented. The first body segment is hemispherical in form, with a distinct median frontal depression. The oral orifice is situated ventrally, and the mouth parts are exceedingly minute. The tracheal system comprises two pairs of large open spiracles on the thorax and an indistinguishable number of minute ones on the abdomen.

During the early part of this stage the attachment to the ventral integument of the host is retained. Later the mature larva lies free in the body and, when preparing for pupation, orients itself with the head toward that of the host and with its ventral side upward. The body contents of the host are entirely consumed, and no solid meconium is cast by the larva.

The pupa, which is of normal form, lies in the above position also. When the pupal skin is cast, the adult parasite cuts a circular emergence hole through the dorsal integument of the host body. In every instance noted this emergence hole has been situated at the anterior end of the body.

In view of the high percentages of parasitization attained by Eretmocerus in Malaya and Cuba, it is inevitable that a heavy loss should occur through superparasitism. No apparent discrimination is exercised by the female in the choice of hosts, and as many as eight

first and second stage larvae have been found beneath a single host individual. Only one of these, however, can ever attain maturity. No instance has been noted of more than a single larva within the host body, nor is more than one entry hole ever evident, so that it would appear that the larva first effecting entry is able to prevent the entry of those remaining, though no explanation is offered as to how this is accomplished. The death of the superfluous larvae takes place outside of the host body and in their second stage. In infestations showing the high degree of parasitization which is often attained under field conditions this mortality may represent the greater portion of the reproductive potential.

Emergence of the adults of Eretmocerus occurs very largely during the early morning hours, a habit common to most parasitic Hymenoptera of diurnal habit. Mating takes place upon the foliage very shortly thereafter, and oviposition may ensue the same day. The females are most active upon the foliage during the period from 10 a. m. to 2 p. m., during which time the greater proportion of oviposition is accomplished. In mid-afternoon they largely disappear from the trees.

Dissections of gravid females have shown a total of approximately 100 fully mature eggs in the reproductive system, with a varying total in the earlier stages of formation. Oviposition continues over a period of 7 to 10 days, and it is estimated that a least 200 eggs are laid during this time. Counts made of emerging adults from several colonies gave a sex ratio of 1.99 : 1, the females predominating, and the reproductive potential is consequently 135 or somewhat higher.

The percentages of parasitization of the two sexes of the blackfly by Eretmocerus are approximately equal, though some deviation from this is shown. In five groves from which counts were made, these totaling 7,711 individuals, the sex ratio of *A. woglumi* ranged from 1.26 : 1 to 1.68 : 1, with the mean at 1.52 : 1, the females predominating in each case. In two of these groves the blackfly was very heavily parasitized by Eretmocerus. The sex ratios of the host in these groves were 1.26 : 1 and 1.51 : 1, while those of the parasitized individuals only were 1.09 : 1 and 1.52 : 1, respectively. The oviposition and developmental habits of the parasite present no basis for any departure from the law of chance occurrence in the selection of hosts.

Owing to the peculiarities in the life history of Eretmocerus, it is possible to recognize parasitized hosts in any stage and to distinguish them from such as may be unparasitized or are attacked by Prospaltella or Encarsia. This extends even to the empty pupal case from which the adult parasite has emerged. Those Aleurocanthus larvae or pupae upon which the parasite is in the egg or the first two larval stages may be recognized by the actual presence of these forms on the leaf surface beneath the body, while such as contain the more advanced stages within the body reveal their presence by the ventral entry hole, surrounded by a light brownish area, contrasting markedly with the normal black coloration of the integument. This point of entry is also readily visible in the empty pupal shells. *Prospaltella divergens*, *P. smithi*, and *Encarsia meraeti* are

true internal parasites, and consequently no immature forms can be found beneath the host body, and the distinctive entry hole is lacking.

PROSPALTELLA DIVERGENS SILVESTRI

Prospaltella divergens is of common occurrence throughout Malaya, Java, and Sumatra. It attacks practically every species of the genus Aleurocanthus present in these sections. Upon *A. woglumi* it is the dominant parasite at Singapore, but is superseded by *Eretmocerus serius*, and occasionally by *P. smithi* also, in some other localities in Malaya, in which it has been studied. At Medan, Sumatra, it is by far the most common species attacking *A. spiniferus*, representing approximately 90 per cent of the parasite population upon this host. However, no instance was observed of effective control of *spiniferus*, as this aleyrodid attained a destructive status in many groves and the percentage of parasitization was seldom high. The third species of Aleurocanthus occurring upon citrus in Malaya and the Dutch East Indies, *A. citriperdus*, also serves as a host of this parasite. In general its attack upon *A. woglumi* is more extensive than upon any of the other hosts noted.

Oviposition occurs in the primary larval stage, and emergence of the adult is from the host pupa. A single generation is produced upon each one of the hosts, as compared to two in the case of Eretmocerus. *P. divergens* (fig. 10) is represented by females only, as progeny are of the female sex alone when parthenogenetic reproduction occurs, which is the normal condition. What had previously been considered to be the males of this species later proved to be those of *P. smithi* instead. Not a single instance of mating has been observed in the field in the case of *P. divergens*, while with other species it may frequently be seen.

The adult females are quite inactive in habit and do not have nearly the capabilities for dispersion exhibited by Eretmocerus. In the field they may be observed in numbers upon the young foliage bearing eggs and early stage larvae of the host, apparently awaiting the attainment of the proper stage of the latter for oviposition.

In the three consignments of parasite material forwarded from Malaya during 1930 and 1931 *P. divergens* was present in varying numbers. From the first shipment 34 females were obtained, but no progeny developed from these in the attempted breeding work in Cuba. The second lot yielded 43 females at New York, but none of these reached Cuba alive. The third shipment consisted almost solely of this species, and a total of 750 females emerged during the month following arrival in Cuba. Dissections of females from the cages before liberation revealed mature eggs in normal numbers in the reproductive system. Some of the adult females were confined in transparent cellulose-paper and cloth bags upon heavily infested orange seedlings in the insectary, while others were similarly caged upon suitable branches in the field. A lesser number were liberated directly upon the trees in two groves in which the host was largely in the egg and early larval stages. In all cases the females were observed to attack the first-stage larvae almost immediately after becoming aware of their presence upon the foliage.

This last consignment arrived at Habana on June 3, and the emergence of the adults, with the attempted colonization and rear-

ing, took place during the month following. The first half of June was relatively dry, but the latter half and July presented a relatively high humidity and rainfall, the climatic conditions thus being similar in all apparent respects to those of the native habitat of the parasite in Malaya.

In spite of the fact that the host material provided was abundant in quantity, in all stages of development, and attained maturity normally, and that climatic conditions were apparently ideal, not a

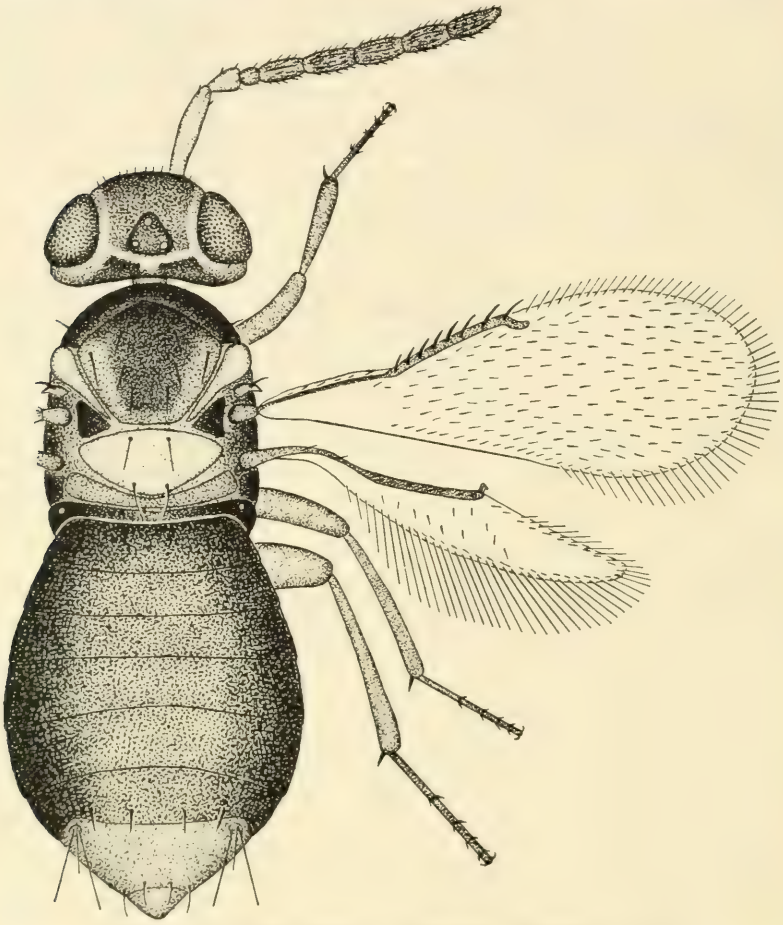

FIGURE 10.—Adult female of *Prospaltella divergens*, × 70

single individual developed from the large number of females used in the attempted rearing and colonization work. This complete and sudden loss of the entire colony was an entirely unexpected development and is difficult to explain. The original stock in Malaya was secured from both *woglumi* and *spiniferus*, and the host material in the Wardian cages on the return trip, upon which at least one generation must have been passed, was *woglumi* of Cuban origin; consequently the loss of the colony can not be attributed to the existence in Cuba of a parasite-resistant race of the blackfly.

PROSPALTELLA SMITHI SILVESTRI

Prospaltella smithi is of general occurrence upon *Aleurocanthus woglumi*, *citriperdus*, and *spiniferus* in the Far East, its distribution being more extensive than that of any of the other species studied. In the original records Silvestri (*10*, *12*) listed it as a parasite of *A. spiniferus* in southern China and *A. woglumi* in Ceylon, and also stated (*11*) that the species effectively controls the latter host in those countries and at Singapore.

The senior writer's observations show this species to be common throughout Malaya and to occur in only relatively small numbers in Java, Sumatra, and Ceylon. In all of the infestations at Singapore it was much less numerous than either *Eretmocerus serius* or *Prospaltella divergens*, while at Muar, Johore, it was approximately equal in numbers to Eretmocerus. In only a single instance, this being on a few small trees at Kuala Lumpur, was *P. smithi* found to occupy the dominant rôle among the parasites of *A. woglumi*. In general it may be rated as third in importance in the series, being preceded by the two species above mentioned.

Prospaltella smithi (fig. 11) was introduced into Japan from southern China by Silvestri in 1925 in an effort to control *A. spiniferus*, which had become exceedingly destructive to citrus in Kyushu. Kuwana and Ishii (*9*) report that four generations are produced each year and that a field parasitization of 74.2 per cent has been attained.

Oviposition by *P. smithi* takes place largely in the primary larval stage of the host, though females have frequently been observed to attack the later larval stages also. The adult emerges from the host pupa. There is a single generation to each one of the host, and this explains the development of only four generations during the year in Japan as compared with six in Malaya, the retardation in development during the cooler portions of the year being correlated with that of the host.

A considerable number of this species were included in the last two parasite shipments from Malaya to Cuba, but development in the Wardian cages en route was very unsatisfactory. In the final consignment a total of 1,220 females were reared from Malayan hosts, largely *A. woglumi*, and liberated in the cages, yet upon arrival in Cuba the total emergence was only 15 females, and these were emerging over a period of several weeks. In the preceding shipment, which was held at New York, only the adult parasites being forwarded to Cuba, 51 females were reared, but not a single one was alive upon arrival at the laboratory. In this case the original parasitization was secured by placing the infested seedlings in a tree in the field upon which the adult parasites were known to be abundant. The better results thus obtained would indicate that the Wardian cages do not provide conditions conducive to extensive oviposition.

PROSPALTELLA SPP.

The various parasites reared from *Aleurocanthus spiniferus*, *citriperdus*, and *woglumi* at Medan, Sumatra, included a small proportion of what has been determined as a new species of Prospaltella.

Its normal host is apparently *A. citriperdus*, and only an occasional individual was reared from *A. woglumi*. This species was not encountered in any of the other collecting localities in Sumatra or Java.

At Colombo, Ceylon, an additional species of Prospaltella was reared from pupae of *A. woglumi*. No biological observations were made upon either of these two species.

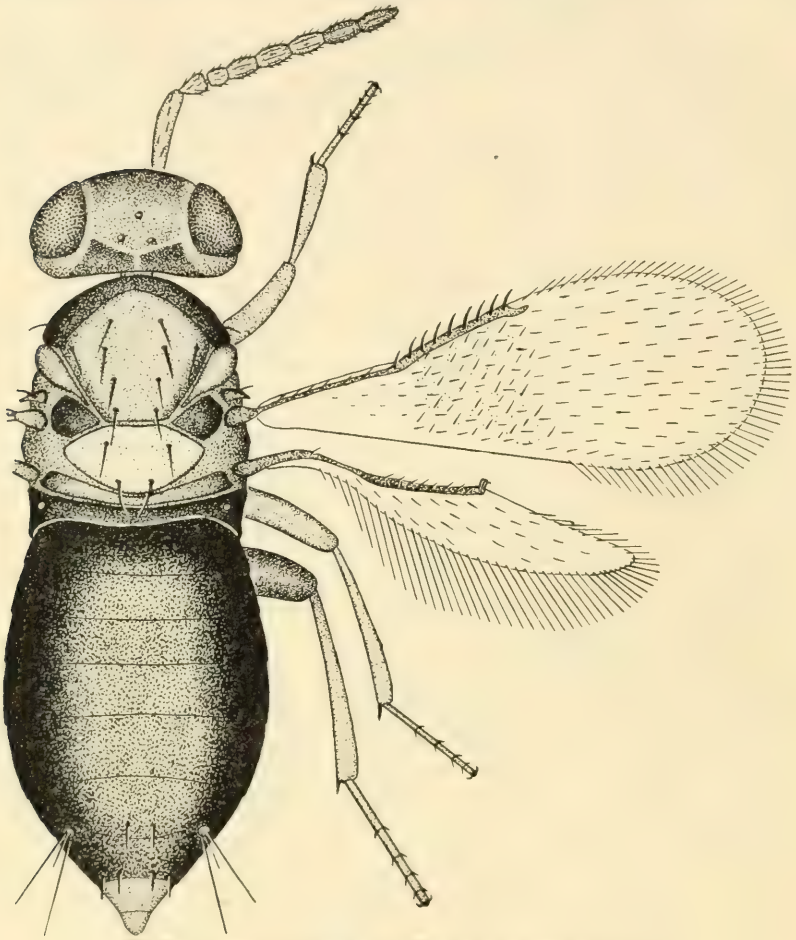

FIGURE 11.—Adult female of *Prospaltella smithi*. × 70

HYPERPARASITES

ABLERUS MACROCHAETA SUBSP INQUIRENDA SILVESTRI

Ablerus macrochaeta subsp. *inquirenda* (fig. 12) has been taken very abundantly as a hyperparasite of all Aleurocanthus in Malaya, Siam, and the Dutch East Indies, and in small numbers in Ceylon. It attacks *Eretmocerus serius*, *Encarsia merceti*, and the various species of Prospeltella which attack the above host genus. A few individuals were also reared from *Amitus hesperidum* Silv., para-

sitic on *A. citriperdus* in Sumatra. Among the various sections in which these parasites have been studied the greatest mortality was found to be effected upon *Prospaltella divergens* at Medan, Sumatra. In general it may be estimated that the loss among the various primary parasites in tropical Asia, due to attack by this secondary species, is approximately 50 per cent.

Development of this subspecies takes place internally in the body of the mature larva or pupa of the primary host, more particularly, however, in the first-named stage. Blackfly pupae from which *inquirenda* have emerged can not be distinguished from those which

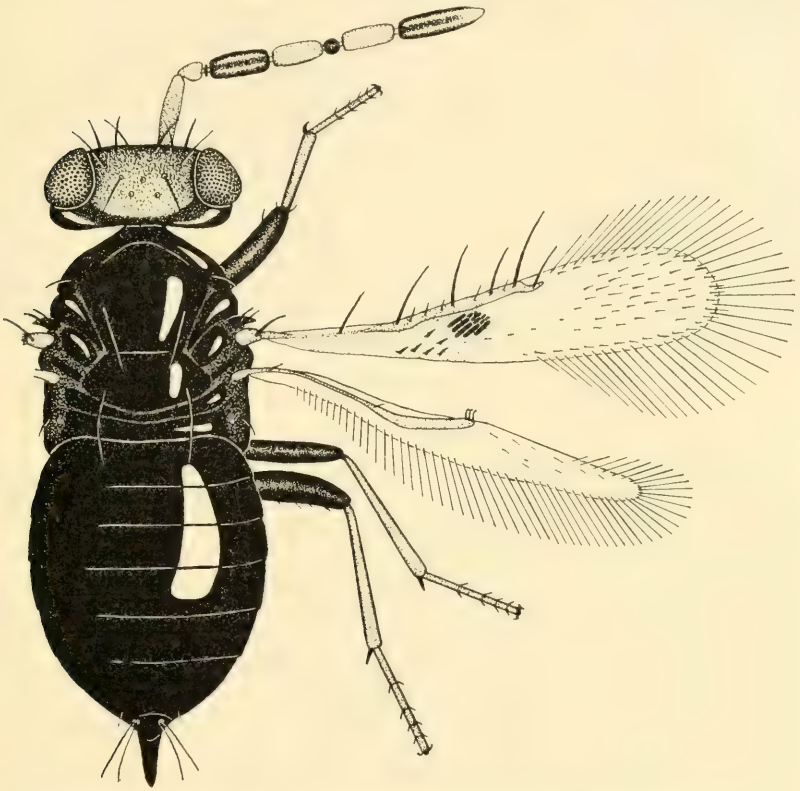

FIGURE 12.—Adult female of *Ablerus macrochaeta* subsp. *inquirenda*, × 65

have yielded the primary parasites, though in the latter case the emergence holes are much more constantly in the anterior end of the body.

Silvestri (*12*) described *Alberus macrochaeta* as being reared from pupae of *Aleurocanthus inceratus* Silv. in Indo-China and stated that it was probably parasitic upon *Prospaltella opulenta* Silv.

ABLERUS CONNECTANS SILVESTRI

Silvestri (*12*) records the rearing of *Ablerus connectans* from pupae of *Aleurocanthus woglumi* in Ceylon. Its true relation to the blackfly is uncertain, but from the limited observations possible

during the senior writer's visit to Ceylon in 1930 it appeared to be secondary. The mortality effected by this and the first-named species was approximately 50 per cent, thus reducing the numbers of the primary parasites to the same extent as does *A. macrochaeta* subsp. *inquirenda* in Malaya.

PREDATORS IN TROPICAL ASIA

The predators of *Aleurocanthus woglumi* and others of that genus in tropical Asia represent a large number of species and an exceptional range of insect groups. As is to be expected, those most frequently noted, and representing the greater number of species, are the coccinellid beetles. Of this family four species are here listed as being primarily predators of Aleurocanthus, and one as an occasional predator. Of exceptional interest, though of little actual importance from the point of view of biological control, are the two representatives of the dipterous family Drosophilidae and the one species of the lepidopterous family Pyralidae.

This abundance in the number of species, however, does not indicate a corresponding effectiveness in control. In aggregate effect the predators represent one of the least important of the factors affecting *Aleurocanthus woglumi* in its native habitat. An exceptional circumstance is the apparently greater restriction in the choice of hosts than is exhibited by the parasites.

COLEOPTERA

Cybocephalus sp.

The nitidulid *Cybocephalus* sp. was found as a predator of Aleyrodidae in only a single instance, it being noted as attacking a mixed infestation of *Aleurocanthus citriperdus* and *woglumi* at Buitenzorg, Java, in April, 1931. The larvae are pure white in color and in general appearance much resemble those of *Scymnus* sp. near *pallidicollis* (p. 41), though none was observed to carry the dorsal pad of cast host skins as does the latter species. Feeding by the larva is restricted largely to the later larval and pupal stages of the blackfly. These larvae are sluggish in movement and remain upon the same leaf throughout the feeding period. Pupation occurs in a cell in the soil rather than upon the foliage.

Approximately 200 eggs and larvae were collected, and the greater portion of these placed upon well-infested citrus seedlings in Wardian cages for shipment to Cuba. The remainder were provided with food in vials and with light soil for pupation. The few adults which later emerged were also placed in the cages. No reproduction took place en route, and examination of the cages upon arrival failed to reveal the species in any stage.

Cryptognatha sp.

GENERAL

The coccinellid *Cryptognatha* sp. is exceedingly uncommon as a predator of Aleurocanthus in tropical Asia. During the entire course of the investigations in Malaya it has been encountered upon only two trees, both of which were at Kuala Lumpur, though sepa-

rated by about 20 miles. The host in each case was *A. woglumi* only, and in each instance Cryptognatha contributed materially to its control. In view of the effectiveness evidenced under these circumstances, the species was considered to be of sufficient importance to warrant introduction efforts, as the limiting factors responsible for its rarity in Malaya may not operate in Cuba and the other infested sections of the New World.

In the spring of 1931 a small number of adults and larvae were observed in an infestation of *A. spiniferus* at Medan, Sumatra.

The consignment of parasite material assembled at Kuala Lumpur and shipped in August, 1930, included about 100 adult beetles of this species. Owing to the scarcity of host material of the very early stages available in the consignment, these beetles were retained in vials and fed upon sugar solution from the time of collection, throughout July, until September 2, at which time 38 were still alive. On this date 20 of these were placed in one of the cages for rearing, as it was improbable that the remaining number could be retained alive in the vials until arrival in Cuba. Oviposition took place quite generally en route. A total of 59 adult beetles emerged and were forwarded from New York to Cuba during late September and early October, 1930, and of this number 42 arrived alive.

Three generations were produced in the insectary in Cuba from this original material before field colonization was started. The first liberation, comprising 227 larvae in various stages of development, was made December 1, 1930, on a group of well-infested trees at Santiago de las Vegas, and further liberations of larvae and adults have been made since that time. In the original colonization work upon this species it was thought that better results might be obtained through the liberation of larvae than of adults, thus eliminating considerable rearing work in the insectary and permitting the maintenance there of a much smaller stock of host material. The results, however, were very unsatisfactory, as the greater proportion of the larvae failed to remain on the foliage upon which they were placed, while others, particularly of the earlier stages, were carried away by ants. Definite establishment of the species was secured only by the liberation of adult beetles.

The species is now well established in several localities in Cuba, and distribution is being extended to the outlying Provinces. The development of the early field colonies indicates that under certain conditions this predator may be of considerable value, though because of its habits no reliance can be placed upon it. In one grove of 2,000 heavily infested orange trees near Hoyo Colorado 127 adults were liberated in late January and early February, 1931. The increase thereafter was very rapid, and by August the grove was considered to be commercially clean. *Eretmocerus serius* was also present in this grove, though in such small numbers as to contribute very little to the outcome. The overlapping host generations maturing in late May, June, and early July had yielded a large brood of adults, and oviposition by them was very extensive. The attack by the adults and larvae of Cryptognatha upon the eggs and first-stage larvae was so thorough that very few lived beyond the latter stage.

The above development indicates that the predator is able to overcome a heavy infestation in an even shorter period than is Eretmocerus. In other groves, however, a comparable result was not secured and no appreciable reduction in host numbers has been effected. What is apparently a weak point in the habits of this predator is its almost complete disappearance from the groves when the host population becomes reduced. In the grove mentioned hardly a single individual of any stage could be found in early August. Both in Malaya and Cuba it has been noted that this species is practically never found upon trees bearing a light or only medium infestation. Owing to this fact the blackfly may again attain a destructive status before the beetle population increases to the required extent.

The exceedingly voracious habits of both adults and larvae give a field effect much greater than the number of individuals present upon the trees would lead one to expect. A single larva is able to clear a heavily infested leaf of eggs and first-stage larvae in a surprisingly short time. It is estimated that a beetle population of 100 adults upon a medium-sized tree, with a proportionate number of larvae of the various stages, is able to check effectively and quickly a heavy infestation in the egg and first larval stages.

In view of the uncertain habits of the species, Cryptognatha may be considered as an aid in the reduction of the initial heavy blackfly infestations, but can not be a satisfactory substitute for Eretmocerus in the permanent subjugation of the pest.

LIFE HISTORY AND HABITS

The egg of this species of Cryptognatha is 0.4 mm in length, 0.25 mm in width, approximately equal in width at each end, and with the poles smoothly rounded. It is translucent white in color, and the surface bears a delicate incrustation of transparent wax which, shortly after the deposition of the egg, assumes a pebbled appearance.

These eggs are laid singly and lie horizontally upon the leaf instead of standing vertically upon the posterior pole. They are usually placed immediately adjacent to well-developed blackfly larvae or in the crevice between larvae that lie very near to each other, the latter being the favorite position. Where all stages of the blackfly are present they may also be found upon leaves bearing eggs only. In a number of cases noted the eggs have been found on foliage heavily infested with red spider (*Tetranychus telarius* L.), though lacking the blackfly, and often among or beneath the webs.

The first-stage larvae are grayish to grayish brown in color, becoming somewhat more brownish in the later stages, which also have a pronounced median dorsal stripe of a lighter shade. These larvae are exceedingly active in all stages, moving frequently from leaf to leaf, and may wander to all parts of the tree during the feeding period. When full grown they attain a length of 4.5 mm. The mature larvae (fig. 13, B) often feign death and fall from the tree when disturbed, a habit which may be responsible for an extensive loss because of their inability to reach infested foliage again.

The pupa is yellowish and tinged with the red of the body contents. The basal half of the abdomen is enveloped by the cast larval skin. Under field conditions in Malaya pupation invariably takes

place in the soil or in rubbish beneath the tree, and not a single pupa was ever found upon the tree itself. In Cuba, however, the pupae may often be found upon the leaves. The normal pupation habit may be considered as disadvantageous in comparison with leaf pupation, in that a much greater mortality probably occurs through the blowing away and decay of dead leaves and rubbish beneath the tree, from burial in the soil by heavy rains, and through the attack of ants and various other predators living on or beneath the soil surface.

The adult beetle (fig. 13, A) is considerably larger than most of the other species of Coccinellidae which habitually prey upon Aleyrodidae, it being 2.6 mm in length. The general color is black, with

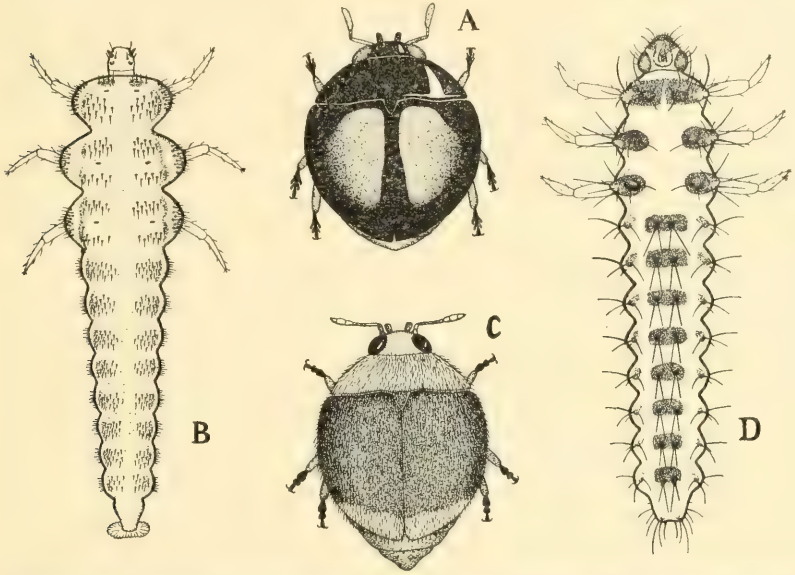

FIGURE 13.—Coccinellid predators of the citrus blackfly: A, *Cryptognatha* sp., adult, × 10; B, mature larva, × 14; C, *Scymnus smithianus* adult, × 18; D, mature larva, × 24

a large red spot on each wing cover which, in outline, corresponds to that of the wing cover. These adults are found largely upon the outer foliage of infested trees and feed by preference upon the early stages of the blackfly. Like the larva, the beetle itself feigns death when disturbed.

Under normal summer conditions the life cycle of Cryptognatha is complete in 18 to 20 days, of which time 4 days is required for incubation of the egg, 10 to 12 days for the larval stage, and 4 days from pupation to the emergence of the adult.

In view of the above life cycle it is seen that two full generations can develop during the period covered by a single generation of the fly. For that reason development in the field, where the blackfly itself has distinct rather than overlapping generations, may be either upon the eggs and early larval stages or upon the late larval and pupal stages. Where the beetles appear at the time of fly oviposition they feed extensively upon the eggs and primary larvae and oviposit

among them. The increase in this generation is usually greater than in the following one, where feeding by both adults and larvae is upon the more mature stages. Under the latter conditions, however, development is somewhat more rapid and the individuals attain a greater size.

SCYMNUS SMITHIANUS SILVESTRI

GENERAL

The coccinellid *Scymnus smithianus* was first found on a small group of young lime trees in a garden at Kaban Djahé, Sumatra (elevation 4,200 feet), in February, 1930, and not a single specimen has been found in any other locality since that time. In late July 65 adults and larvae, all that could be found upon the original trees, were collected for inclusion in the August shipment to North America. In view of the great scarcity in numbers in the original habitat, and the limited distribution of the species, it has not been considered to be of any great potential value against the blackfly in North America, but was included in the shipment largely for experimental purposes. Upon arrival in New York the latter part of September the first cage generation had been completed, with 27 adults present in the cages. These were forwarded to Cuba, and insectary rearing was started. The insectary conditions provided there, which had been found suitable for other coccinellids and for the internal parasites, were apparently not well adapted for this species, and the stock eventually declined in numbers during the following month, without oviposition, until only a single female remained. This lone female, however, proved to be fertile, and from this beginning the stock was built up. The first field liberation, comprising 10 adults, was made in January, 1931, and during the following six months colonies have been distributed in various sections. While the species is now probably established in Cuba, it is not felt that it will be of any appreciable value in the control of the blackfly. This is due to the fact that its general habits are evidently not suited to the conditions prevailing in Cuba at certain seasons. Development and increase in the field were satisfactory during the late winter and spring following the early colonizations, but during the summer period, in which the blackfly population increases very rapidly, reproduction largely ceases. This predator apparently requires somewhat lower temperatures and a minimum of rainfall, and this is the condition which existed in the single mountain locality in Sumatra in which it was found.

LIFE HISTORY AND HABITS

The eggs are normally deposited singly among clusters of the later stages of the blackfly, usually in contact with one or more individuals. Often, however, they are placed within empty pupal cases from which the flies have emerged. This latter oviposition habit is known to be constant among certain other coccinellid species which are predacious upon Aleyrodidae.

The larvae in all stages are markedly conspicuous and can be readily distinguished from other species attacking Aleyrodidae in Cuba and Panama by the color, as each body segment bears dorsally

a transverse black band broken medially on the thorax, upon a white background. Fully grown individuals (fig. 13, D) measure 2.8 mm in length. The larva throughout its life is very inactive and practically never moves from the leaf upon which the egg was laid. Feeding takes place largely upon the late larval and pupal stages of the blackfly.

The pupa is largely black, with the basal half of the abdomen enveloped by the cast larval skin. Pupation occurs in situ on the leaf, among the blackfly clusters.

The adult beetle (fig. 13, C) is black in color, with the thorax yellow, and measures 1.7 mm in length. It it very sluggish and is apparently incapable of rapid dispersion in the field. In Sumatra the colonies were usually confined to limited portions of the tree, though the *A. citriperdus* infestation was general. In the rearing work in Cuba the period elapsing from emergence of the adult to oviposition has been considerably longer than is the case with Cryptognatha, and the rate of oviposition, as well as the total number of eggs laid, has been much lower.

Under insectary conditions the period of development from egg to adult has been 18 to 21 days, with the time of incubation averaging 6 days, the larval stage 9 days, and from pupation to emergence of the adult 4 to 5 days.

In its native habitat in Sumatra this species is heavily attacked, in both the larval and pupal stages, by *Aminellus* n. sp. near *niger* Masi, of the chalcidoid family Encyrtidae.

Scymnus sp. near pallidicollis Mulsant

Among the various coccinellids found attacking Aleurocanthus in tropical Asia, this species of Scymnus is the only one of general distribution, and is found in practically every infestation of the above genus. Its degree of attack varies greatly with the fly species present, a great preference being shown for *A. citriperdus*, followed by *A. spiniferus*, while only occasional individuals have been noted to prey upon *A. woglumi*.

The greatest numerical abundance of this species under field conditions was noted in the heavy infestation of *A. spiniferus* at Medan, Sumatra, where several larvae and pupae could usually be found upon practically every infested leaf. In spite of these numbers, however, it appeared to effect little appreciable diminution in the fly population on the trees, the latter being maintained at nearly the maximum level until decimated by fungous disease during the rainy season.

Several efforts have been made to import this predator into Cuba, though with negative results each time. Both adults and larvae have been confined in Wardian cages with an ample supply of *A. woglumi* in all stages for feeding en route, but in no instance did reproduction occur.

Life history and habits

Both the larvae and adults of this Scymnus feed upon all of the immature stages of Aleurocanthus, though the beetles confine themselves largely to the early larval stages.

The egg is pale lemon, 0.5 mm in length, 0.27 mm in width, with both ends smoothly rounded, and the surface bearing small, raised dots widely separated. Oviposition always takes place in the immediate vicinity or among the fly clusters, and the eggs may be found either among immature larvae, on the leaf surface adjoining the mature larvae or pupae, directly upon the body of the larva or pupa in the depression within the lateral row of spines, or centrally upon the dorsum beneath the cast skin. Occasional instances have been noted in which the egg was laid within the empty pupal shell. Where oviposition occurs in a colony of nearly full-grown Aleurocanthus the more normal position of the egg is directly upon the body.

The larva in all stages is lemon yellow to white, the final stage being nearly pure white. The dorsum of the body is clothed with numerous long hairs. Where feeding takes place upon eggs or young larvae they may be entirely consumed, but the more general feeding habit is upon the mature larvae and pupae, in which case a puncture is made in the body wall and the fluids are sucked out. It is consequently impossible to distinguish the individuals which have thus been killed from others which have died from other causes. In the course of feeding upon the later stages the cast skin of the prey, which rests dorsally upon the body of the succeeding stage, is disturbed and becomes entangled in the long dorsal body hairs of the predator. In this way the larva may accumulate a considerable mass of these cast skins upon its body, thus forming a loose and irregular dorsal shield. This, however, has no protective function, such as has been attributed to the pad carried by the larvae of some of the lacewing flies.

The larva is inactive throughout its period of development and very seldom moves from the leaf upon which the egg was laid. In view of the size of the body in relation to that of the mature Aleurocanthus, an average cluster of the latter is adequate for feeding during the entire stage, and there is thus little incentive to movement.

Pupation takes place in situ upon the leaf at the point where feeding ceases. The cast larval skin, with its collection of blackfly exuviae, largely covers the dorsum of the pupa.

The life cycle from egg to adult is complete in 18 to 21 days. Incubation of the egg requires 5 days under climatic conditions having a temperature range from 75° to 90° F. The larva pupates 8 to 10 days after hatching, and 5 to 6 days elapse before the emergence of the adult.

Scymnus sp.

Scymnus sp. is of general distribution throughout the Malayan region and is, in both the adult and larval stages, a general feeder upon various diaspine Coccidae and Aleyrodidae. It is often found upon trees infested with *Aleurocanthus citriperdus*, *spiniferus*, and *woglumi*, but is considered to be only an occasional predator upon these, rather than being restricted to them, as are the other coccinellid species discussed herein.

The adult beetles are very similar in general appearance to those of *Scymnus* sp. near *pallidicollis*, but may be distinguished from them by the lack of the lighter-colored anterior margin of the elytra.

LEPIDOPTERA

CRYPTOBLABES GNIDIELLA MILLIÈRE

The pyralid predator *Cryptoblabes gnidiella* has been found as an enemy of the blackfly in only two instances. The first was in March, 1931, in a grove of young citrus trees near Muar, Johore, in which a number of the trees were heavily infested with *A. woglumi*. The larva, which is purplish in color, forms a light web over the undersides of heavily infested leaves, and beneath this web it moves about among the masses of blackfly larvae and pupae. Pupation occurs in situ in a fold or depression in the leaf. On a few trees these larvae and pupae could be found on practically every infested leaf. The second collection locality for this species was at Medan, Sumatra, upon *A. citriperdus*, though the number observed was very small.

Laboratory experiments established the fact that the larvae feed upon the living blackfly in the late larval and pupal stages. From field observations, however, it would appear that the species is, to an uncertain extent, a scavenger rather than a predator. In several instances young larvae were found to be active and able to attain maturity in colonies from which adult emergence had been completed some time previously.

An examination of the literature relating to *C. gnidiella* shows that it attacks cotton and a variety of other plants in Egypt and grapevines in southern Europe, and it is listed as a citrus pest in Spain. Dudgeon (*4*), however, mentions it as being possibly an enemy of the bollworm *Earias insulana* Boisd. in Egypt, while *C. prolucella* Hamp. is on record as feeding upon *Coccus viridis* (Green) in Ceylon.

DIPTERA

ACLETOXENUS INDICA MALLOCH

GENERAL

The predacious drosophilid *Acletoxenus indica*, originally described from southern India, is of fairly common occurrence in infestations of Aleurocanthus and various other aleyrodid genera in Java. It was found most abundantly at Bandoeng attacking *Aleurocanthus citriperdus* and, to a lesser extent, *A. woglumi* also. Where both species occurred upon the same tree the greater proportion of Acletoxenus eggs and larvae were always to be found among the *citriperdus* clusters.

In Malaya and Ceylon occasional empty puparia, identical in form and appearance with that of this species, have been noted in colonies of several genera of Aleyrodidae, but no adults could be secured for determination. Likewise, a few empty puparia of similar appearance have been seen among several aleyrodid clusters upon jungle plants in Cuba.

At Bandoeng, Java, *Acletoxenus indica* is the dominant predator upon Aleurocanthus, though it is of little importance from the standpoint of control. In other localities the number found upon infested trees was very small.

Under field conditions in Java *A. indica* is heavily parasitized by a species of Myiocnema. The egg of this eulophid must be laid either

in the host egg or young larva, though the adults emerge from the puparia, as isolated larvae have often yielded the parasite. From 220 eggs, larvae, and puparia collected at Bandoeng in April, 1931, 68 per cent yielded Myiocnema instead of the fly. The exposed position of the egg, if this is attacked, and the very sluggish habits of the larva, render the species particularly susceptible to parasite attack.

Two attempts have been made to effect the importation of Acletoxenus into Cuba, but both have failed. The confined quarters provided in the Wardian cages, as well as the reduced light therein, apparently were unsuited to the habits of the adult flies and practically no oviposition occurred. The first shipment was upon croton plants heavily infested with a species of Dialeurodes and the second upon citrus bearing an ample supply of blackfly. Examination of both shipments upon arrival showed no living flies in any stage and only an occasional empty puparium. In the last shipment 50 larvae in various stages of development, in addition to 15 adult flies, were placed in the cage at the time of shipment, but so far as could be determined by examination of the infested plants en route, not a single egg was laid.

LIFE HISTORY AND HABITS

The egg of *Acletoxenus indica* is 0.4 mm in length and 0.2 mm in maximum width at the posterior pole, and tapering somewhat toward the anterior end. The surface is covered with a white waxy incrustation which is somewhat roughened with irregular and at times indistinct reticulate markings. Oviposition occurs during midday, and the eggs are placed singly upon the leaf surface adjacent to a late-stage larva or pupa. It lies horizontally and adheres firmly to the leaf.

The larva in its early stages is translucent white, but later takes on a distinct greenish hue due to the body contents being visible through the transparent integument. Feeding occurs largely upon mature larvae and pupae. The larva is quite inactive and never moves from the leaf upon which the egg was laid. Such movement is unnecessary in view of the fact that a single cluster of average size provides sufficient food material to bring the larva to maturity. Pupation occurs in situ upon the under surface of the leaf.

The larvae of this predator apparently secrete over the body a fluid substance of a decidedly mucilaginous character, and in the later stages this serves to attach particles of extraneous matter to the body, particularly on the dorsum. Many mature larvae carry a large number of Aleurocanthus eggshells in this way, and these may also be found upon the puparium.

The puparium is 2.8 mm in length and of the form shown in Figure 14, B. Its ventral surface is flat and adheres strongly to the leaf surface. During the early portion of the pupal period the greenish color of the body contents shows distinctly through the semitransparent integument, and later the large eyes of the developing pupa, which are deep red, may be distinctly seen. Emergence is effected by the breaking away of the distinct lid at the anterior end. The empty puparium is white.

The adult fly (fig. 14, A) is conspicuous upon the foliage because of its black, yellow, and white markings. The general habits of this species correspond to those of other species of the family.

The duration of the life cycle has not been definitely ascertained, but eggs collected in the field have yielded adult flies in approximately two weeks.

Acletoxenus sp.

A second species of Acletoxenus was found only in very small numbers in an infestation of *Aleurocanthus citriperdus* and *woglumi* at Kaban Djahé, Sumatra, while empty puparia of what was presumed to be the same species were occasionally noted at Medan.

The egg and larval stages, as well as the general habits of the species, are identical with those given for *Acletoxenus indica* from Java.

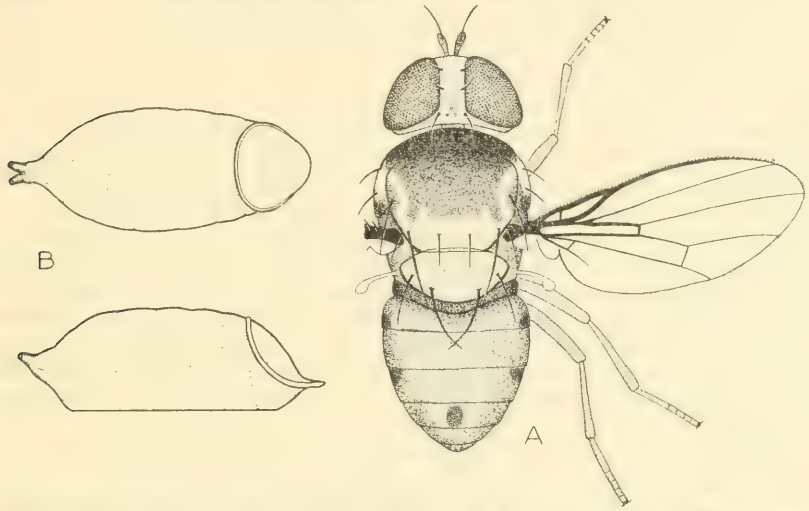

Figure 14.—*Acletoxenus indica:* A, Adult female, × 24; B, dorsal and lateral views of the puparium, × 16

NEUROPTERA

Chrysopa sp.

While this chrysopid is a general predator upon many insects in addition to *Aleurocanthus woglumi*, it is invariably found in all infestations of Aleurocanthus in the Malayan region. It is of little or no appreciable value in controlling the infestations of blackfly, yet because of its general occurrence it ranks first among the predators of *A. woglumi* in Malaya.

The larva carries upon its body a considerable mass of miscellaneous material, the greater proportion of which, in blackfly infestations, consists of the cast larval skins of its prey.

NATIVE PREDATORS IN CUBA, PANAMA, AND JAMAICA

The original blackfly stock from which the infestations in tropical countries of America originated was apparently entirely free

from natural enemies of any kind, as no parasites or predators native to tropical Asia have been found in any of the American infestations. In all of these sections, however, a number of local predators have become adapted to it.

The predators thus far listed in Cuba comprise the coccinellids *Delphastus pusillus* Lec., *D. pallidus* Lec., *Scymnus ochroderus* Muls., *S. bahamicus* Casey, and *Botynella quinquepunctata* Weise, and the lacewing fly *Chrysopa* sp. Of the above series of Coccinellidae the two species of Delphastus, in both the larval and the adult stages, are normal predators of Aleyrodidae and attack largely the early stages of the prey. At times these species become quite abundant in the field. The adults of *Botynella quinquepunctata* feed likewise upon the younger stages of the blackfly, while the larvae confine themselves largely to the diaspine scales. The adults of *Scymnus ochroderus* and *S. bahamicus* likewise attack the early stages, but the larval feeding habit is as yet unknown.

The lacewing fly *Chrysopa* sp. is found in practically all infestations, but is never abundant.

In Panama the predators listed by Dietz and Zetek (*3*) are *Hyperaspis calderana* Gorh., *H. albicollis* Gorh., *Scymnus thoracicus* For., *S. horni* Gorh., *S. coloratus* Gorh., *S. adspersulus* Gorh., and *Cryptognatha flaviceps* Crotch. The last-named species is said to be the most abundant, but none is of any appreciable value in controlling the pest. During the senior writer's visit to Panama in December, 1930, and January, 1931, the various species of Scymnus were noted to be exceedingly abundant on a group of heavily infested orange trees, their number greatly exceeding that recorded in any locality in Cuba. These trees had been sprayed a short time previously, though rather ineffectively, yet in relative numbers the blackfly had apparently suffered to a much greater extent than the predators.

In Jamaica Gowdey (*7*) records the two coccinellids *Scymnus aeneus* Sic. and *S. cyanescens* Sic. as attacking the blackfly. He also expresses the opinion (*6*) that the fly is to some extent controlled by ant enemies.

FUNGOUS DISEASES

In all of the sections of the Far East in which investigations have been made there has been revealed a marked lack of effectiveness among the fungous enemies of *Aleurocanthus woglumi*. Two of these, of the genera Aschersonia and Aegerita, occur in Malaya, but are exceptionally rare on this host. A single lightly infested tree near Kuala Lumpur at one time showed approximately 10 per cent mortality through the attack of Aegerita, but in all other infestations only occasional diseased individuals could be found. In the three groves in Malaya where one or more trees bore what might be termed heavy infestations of the blackfly, no evidence whatever of fungous attack could be found. This condition is attributed to an evident resistance of *A. woglumi* in Malaya to such attack. Fungous diseases of insects are, in general, very abundant in all tropical localities, and a very high mortality is effected among various Coccidae, particularly in the genera Chrysomphalus, Parlatoria, Lepidosaphes, Pulvinaria, and Coccus, through this agency.

The variation in degree of resistance to fungous attack by different species of the same genus, and upon the same host plant, is strikingly shown in Aleurocanthus, and is responsible, under field conditions, for a marked difference in the seasonal development. *A. woglumi* is very largely unaffected by fungous diseases and increases to the maximum extent during periods of heavy rains and high humidity, and declines numerically during the occasional periods of relatively dry weather. As opposed to this, *A. citriperdus*, in the same localities, experiences an exceedingly heavy fungous attack during the wet periods, often resulting in virtual extinction, and numerical increase occurs only during the occasional dry periods, at which time the fungous becomes largely inactive. This latter cycle also prevails in the case of the heavy infestations of *A. spiniferus* in Sumatra, where a distinct dry season occurs.

In view of the relative scarcity of fungous diseases attacking the black fly in Malaya, and their marked ineffectiveness, the condition in the New World offers an unexpected contrast. In Panama Dietz and Zetek (*3*) record *Aschersonia* spp. and *Aegerita webberi* Fawcett as the species present; Bruner (*2*) gives *Aschersonia aleyrodis* Webber, *A. turbinata* B., and *Aegerita webberi* Fawcett for Cuba; and Gowdey (*7*, *8*) lists *Aschersonia goldiana* Sacc. and Ell., *Aegerita webberi* Fawcett, *Podonectria coccicola* Petch., and *Sphaerostilbe aurantiicola* B. and Br. as attacking the species in Jamaica. Several of these species normally attack various species of Coccidae, and their occurrence upon Aleyrodidae may be considered as doubtful.

In these sections the fungous diseases are present to a varying extent, usually being quite common and at times sufficiently abundant to exert an appreciable check upon the increase of the fly. Heavily infested leaves may be seen upon which practically every individual has been killed by the fungus, this occurring more frequently from attack by *Aschersonia aleyrodis*. These are only occasional and isolated manifestations, however, and the aggregate general effect of these diseases is not nearly sufficient to offset the normal rapid increase of the host during the rainy season.

The much greater prevalence of these fungous diseases in the New World, as contrasted with the condition in the Malayan region, and their markedly greater effectiveness at all times, is in direct opposition to what might be expected from a comparison of the meteorological data for the respective regions. It would be expected that Malaya, with its constant high temperature throughout the year, a high percentage of humidity at all times, and a heavy and fairly evenly distributed rainfall, would present the optimum condition for the development of these fungous diseases to the maximum extent. The extent to which they do appear, however, is far less, than, for instance, in Cuba, where summer rainfall and humidity approximately equal the minimum figures for Malaya, and where the winter is markedly dry.

METHODS OF REARING, SHIPMENT, AND COLONIZATION

PREPARATION OF SHIPMENTS

In the early plans for the forwarding of parasitized blackfly material from the Far East to Cuba it was felt necessary to utilize

noncitrus host plants entirely, due to the fact that practically all nursery stock and field trees in the former region are infested with canker, and the risk of its introduction into Cuba could not be taken. The occurrence of a wide range of host plants in Cuba and Panama, several of which were much favored by the fly, appeared to render this procedure entirely practicable. Principal among these hosts are mango and coffee, both of which have a luxurious foliage which does not drop readily under adverse conditions, a requirement quite essential because of the long period of shipment.

In Malaya the blackfly does not occur normally upon these trees in the field, and their suitability under cage conditions was therefore not certain. Seedlings of both of these plants, as well as of several others which might prove suitable, were infested with the fly to test their adaptability. When these were suspended in infested trees in the field, upon which adult flies were present in abundance, it was found that not a single egg spiral was placed upon them, and likewise very little oviposition occurred under cage conditions. It soon became evident that forced oviposition would be necessary to secure an adequate infestation, and this was finally effected by confining adult flies in transparent cellulose-paper bags upon the individual leaves. These were held in a horizontal position, under a rather dim light, so that the flies assembled upon the undersides of the leaves rather than on the sides of the bag itself.

With the random collection of blackfly adults it was found that only 10 per cent production of egg spirals could be secured in this way. The maximum number of flies available for this work approximated only 2,000 per day, so that the egg total secured during the month in which they were available was not sufficient for the infestation of the number of plants at hand. Up to this time all females found upon the foliage were collected each day, and later at 2-day intervals; consequently a varying proportion were not yet ready for oviposition. Upon transfer to mango or coffee foliage the younger individuals did not adapt themselves to the new food plant and usually died without oviposition. A closer study of the habits of the fly in the field showed that mating and feeding take place almost exclusively upon the young, fresh leaves and that the gravid females then descend to the more mature foliage for oviposition. In consequence of this habit the later collections were restricted entirely to the adults upon the older foliage. Collections made in this way yielded 50 to 60 per cent of egg spirals, as compared with the 10 per cent previously mentioned.

Those plants already infested were kept upon tables in the shade of coco-palm trees outside the insectary to await hatching and the attainment of the proper stage for parasite attack. Parasitization was secured through the liberation of rather large numbers of adult Eretmocerus, with smaller numbers of Prospaltella, directly upon the plants in the open. This was also aided by the attack of the same parasite species emerging from Aleurocanthus present upon coco-palm and other trees in the immediate vicinity.

The host plants infested at this time showed a great individual variation in their suitability for blackfly development. Upon the great majority of coffee seedlings hardly a single individual devel-

oped from the hundreds of egg spirals present upon each plant. The mortality occurred very largely in the first larval stage. Occasional plants yielded fairly good infestations, but these were too few to be of any value for shipment. About two-thirds of the mango seedlings carried a sufficient number of developing larvae to justify their being forwarded, though all were found to be only lightly infested upon arrival in Cuba. It was quite fully demonstrated that these two host plants are considerably resistant to the blackfly in Malaya, and oviposition upon them can be secured only under forcing conditions. In contrast, blackfly stock from Cuba and Panama oviposit and develop readily upon these plants in the open.

In preparations for the second shipment from Malaya the available blackfly material was restricted to the infestation upon a single small tree. This was due to the complete annihilation by Eretmocerus of the infestation which had been previously used. The number of adults available from this one tree was not sufficient to secure the required infestation upon mango by the methods previously employed. As a consequence, native citrus seedlings were utilized as a last resort. These were known to be infested with citrus canker, but it was thought that some method of handling upon arrival could be devised to eliminate any danger of the disease becoming established. However, upon the arrival of this shipment at New York in September, 1930, it was decided that there was too grave a risk of the introduction of canker to permit the further forwarding of the stock under any conditions. It was consequently held in an office building in that city, and only the adult natural enemies were shipped to Cuba. It had been hoped that this could be successfully accomplished by air mail, but this effort resulted negatively, and only the two coccinellid species contained in the consignment arrived alive.

Several varieties of citrus were utilized in this shipment, including lemon, lime, Chinese orange, and pummelo. The young foliage of lemon cuttings proved to be by far the most attractive to the flies, with pummelo ranking second. It was later discovered that the lemon foliage drops very readily when heavily infested, while a number of the plants died through overinfestation, and this plant is consequently not so suitable for shipping purposes as are orange and pummelo.

In infesting these plants it was not necessary to employ the methods previously used with mango and coffee. Instead, they were placed in a series of racks in a frame erected about the infested tree, as shown in Figure 15. The young plants were growing vigorously while the infested tree was somewhat withered because of the dry weather prevailing at this time. As a result of this better physical condition, and the presence of young, fresh foliage, approximately 80 per cent of the total ovipositions by this brood of flies was upon the potted plants rather than upon the tree itself.

The infested seedlings were allowed to remain upon the racks or beneath the tree until the second larval stage was attained. This permitted normal attack by those parasite species present upon the tree.

The scarcity of host material in Malaya, in conjunction with the unsatisfactory results attained with noncitrus food plants in that

region, led to a change in the entire procedure in preparation for the third and final shipment. The use of Malayan blackfly stock and plants was abandoned and, instead, the entire lot of infested plants was taken from Cuba and Panama to Singapore, parasitized

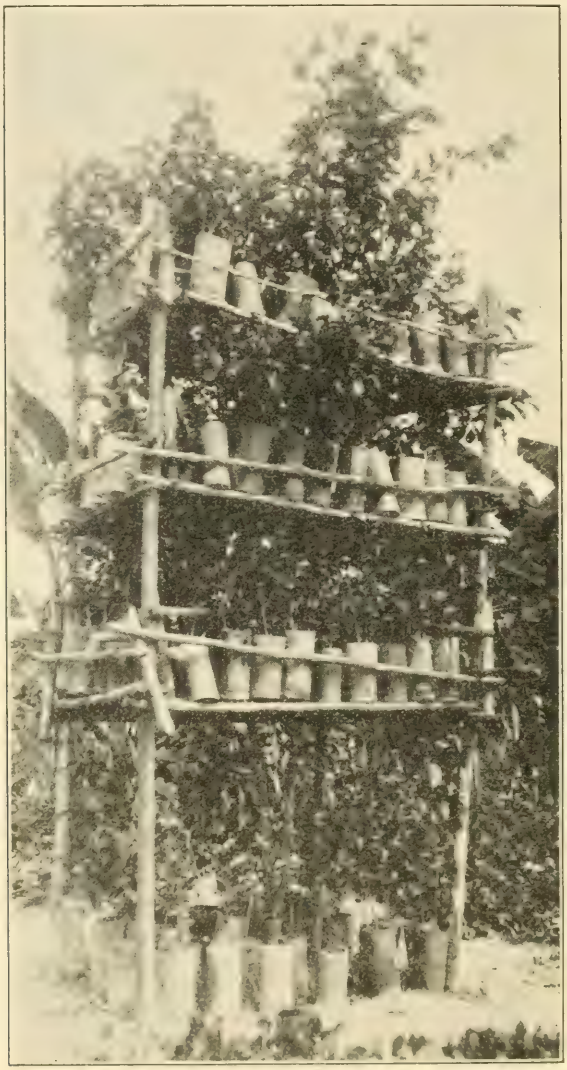

FIGURE 15.—Infesting citrus seedlings in the field in Malaya. The young plants are in bamboo cylinders arranged upon a temporary framework about a heavily infested tree.

there, and immediately brought back to Cuba. This involved a trip of five and one-half months, of which time two months were spent in the collection of parasites and predators in Malaya, Java, and Sumatra, and the remainder was taken up in transit. This method very largely eliminated any risk from citrus canker, as the cases were

kept closed during the stay in Malaya and only adult parasites and predators were placed in them. As an added precaution a thorough inspection for canker was made upon return to Habana.

The food plants used in this shipment were orange seedlings from Cuba, and mango, coffee, and Ardisia from the Canal Zone. A heavy infestation of blackfly was secured upon citrus by covering the entire lot with a light muslin cloth and liberating large numbers of blackflies beneath it. This infestation was later increased, and an overlapping of generations secured, by the direct liberation of additional quantities in the cases. At Balboa, Canal Zone, the infestation upon the noncitrus plants was secured by placing a mass of heavily infested foliage, from which adults were emerging, among the plants. These readily transferred from the withering foliage to the more fresh leaves of the plants provided. The ease with which this was accomplished was in marked contrast to the difficulty experienced with the same kinds of plants in Malaya.

Development upon citrus en route was excellent, and a heavy infestation was maintained until the return to Cuba. The coffee and Ardisia which had been infested at Balboa proved unsatisfactory and were destroyed before arrival at Singapore, while development upon mango was not nearly so good as upon citrus. The large number of blackflies which developed upon the latter plants gave rise to a heavy production of honeydew, with the resultant growth of much sooty-mold fungus upon the foliage. It was found that the periodic washing of the leaves to remove this deposit enabled the plants to carry a much heavier infestation without injury than was otherwise possible.

The physical condition of the plants upon return to Habana was quite good, in view of their having been in the Wardian cases continuously for nearly six months and subjected to considerable handling and various adverse conditions. Considerable new foliage was developing at this time, upon which extensive oviposition by the blackfly was taking place.

In the case of the plants en route the greatest difficulty was experienced in controlling the red spider in the cases. The measures taken, which consisted largely of frequent washing of the younger foliage, were limited by the need for conserving the blackfly and parasites upon the plants, which prevented the utilization of the usual methods of controlling this pest. The bleaching of the foliage due to attack by red spider rendered it unsuitable for blackfly development. By persistant attention the infestation was kept within reasonable bounds, though never eliminated.

The parasitization of this consignment in Malaya was effected by the collection of as large quantities of infested foliage from the field as was possible and the rearing of the parasites contained in the blackfly pupae. These parasite adults were collected daily and transferred to the Wardian cases. In this way the transmission of the citrus canker infection was prevented, as well as infestation by Ablerus, the very destructive hyperparasite which was present in all of the material collected. In general this method did not prove to be so satisfactory as direct parasitization in the field, and only *Prospaltella divergens* reproduced readily under the conditions provided.

Of interest in connection with the rearing methods employed is the comparative adaptibility of the various parasite species to the conditions provided. A few individuals of *Eretmocerus serius*, which had already become established in Cuba through the first shipment, accidentally gained access to the plants of this lot before departure from Habana. Whenever noted in the cages thereafter the adults were destroyed, but in spite of these measures the number which emerged after return to Habana was approximately equal to that of *P. divergens*, of which 2,500 females had been liberated in the cases several months earlier, while 1,200 *P. smithi* were also included and yielded only 15 adults upon arrival.

SHIPPING CONTAINERS AND CARE EN ROUTE

The Wardian cases used in the forwarding of the parasite shipments from Malaya were of the type employed by the Department of Agriculture of the Federated Malay States in their plant ship-

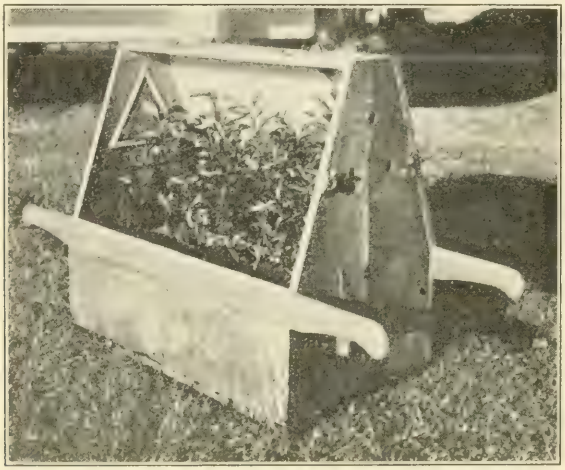

FIGURE 16.—Wardian cage with side open, showing construction, and plants ready for shipment. (Photo by Cuban Agricultural Experiment Station)

ments to England and other distant points. The construction was modified in several respects to suit the requirements of this project, and the general make-up is shown in Figure 16. The wood used was teak, which was ideal for this purpose, owing to its strength, lightness, freedom from warping, and resistance to rot when wet.

There are several essential requirements for Wardian cases when utilized in extended shipments of parasite material upon living plants. Strong construction is necessary to withstand the rough handling received in loading or unloading from steamers. This was well demonstrated in the loading at Balboa of the consignment taken to Malaya on the second trip. The 12 cases were taken from the dock on a lighter and met the steamer in the bay. This steamer did not stop, however, but slowed to half speed, and the cases were hoisted on board in rope slings. Three or four were placed in the sling at one time and dropped on the deck in all positions. In the construction and packing, however, this treatment had been antici-

pated and no damage resulted. These cases were comparatively heavy, weighing approximately 350 pounds each.

Further requirements of these cases are that they shall be insect proof and yet provide sufficient light and air for the normal breeding of the parasites and host insects en route. The needs in this respect vary considerably with the insects dealt with, the blackfly requiring considerable light for normal feeding, mating, and oviposition. The ventilation holes at each end of the case are covered with 90-mesh copper screen. The rusting of this screen produces copper salts poisonous to insects if eaten, but this point is of little importance in the case of the blackfly and its parasites. A fine cotton or silk cloth was tried at one time, but in the Tropics this was very quickly penetrated by ants in their effort to gain access to insect material upon which to feed.

For convenience in examination en route, as well as in the preliminary handling in the insectary, both sides of the cases are removable, though insect proof. This is effected by lining the edge of each cover with heavy felt. During shipment these covers are securely screwed down, but during the rearing work, or on shipboard where frequent examination is necessary, these screws are removed and the covers fastened by a number of window catches instead.

To provide proper light and air in the cases one side is covered with white cloth, preferably a light khaki, canvas, or drill, and the opposite side with heavy celluloid. This latter is much lighter than glass and has the great advantage of being practically unbreakable. Both sides are also covered with metal lath of ¾-inch mesh for further protection.

To prevent warping and discoloration the case is painted, inside and out, with shellac. This has the added effect of greatly reducing the number of spiders which form their webs in the corners of the case, and which feed extensively upon the adult blackflies.

As a protection against damage through overturning, and from the shifting of the contents during handling, the plants are securely battened down in the case by a series of wooden strips extending lengthwise and firmly fastened under pressure.

In the first two shipments from Malaya the plants were placed directly in porous soil in the case, and the surface was then covered with a layer of coco husk. This husk aided greatly in the conservation of soil mixture, while the porous soil insured adequate drainage, without which a saturated condition may develop, resulting in cessation in growth of the plants, root rot, and the possible death of the plants. In the final shipment the plants were transferred to individual clay pots at Singapore, and these were firmly packed in light soil and coco husk. This was more satisfactory in several respects, in that it considerably reduced the weight of the packed case and necessitated less watering. Prepared in this way, a shipment may be six weeks en route and still require no watering during this time.

On shipboard the cases are placed upon the open deck, preferably upon one of the hatches (fig. 17), as this gives less heat radiation than the steel decks. They are well exposed to the wind and with the cloth side facing the sun. Direct sunlight upon the foliage re-

sults in extensive burning. It is only under exceptional circumstances in the Tropics that further protection from sunlight is necessary. When required, this is secured by having a light awning erected over the cases or by placing them in the shade of the ship's superstructure. The usual heavy black tarpaulin for the protection of deck cargo provides too dense a shade and, if not raised considerably above the cases, increases the temperature rather than lowers it, and likewise prevents the free circulation of air.

In times of stormy weather at sea, protection is necessary against salt spray upon the foliage. During the trip to Malaya early in 1931 a period of two weeks of very rough weather was encountered in the Pacific, and the amount of salt spray that was driven through the

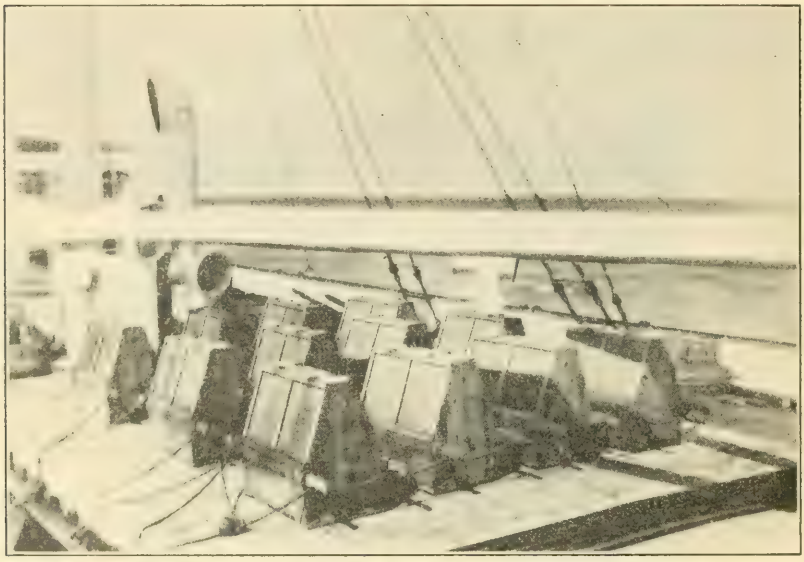

FIGURE 17. Twelve Wardian cases, containing plants infested with the blackfly, on shipboard en route to Malaya

small screened ventilation holes at the ends of the cases and condensed upon the foliage caused extensive burning. Mango foliage was found to be much more susceptible to such injury than citrus.

REARING AND COLONIZATION IN CUBA

In the rearing of the adult parasites from the shipments of foreign origin it is necessary to isolate the infested plants in special emergence cages to insure against the escape of any hyperparasites or other injurious insects which may have been included in the shipment by accident. The type of cage used at the insectary in Cuba in the work upon the blackfly parasites is shown in Figure 18. It consists of a cubical cloth cage so placed as to have only one side facing the light, and with a small door at the back. The parasites are attracted to the light and are collected from the cloth each day. The cage itself is contained in an insect-proof room, so that the possibility

of any insects escaping is quite remote. Upon completion of parasite emergence the shipping cages are either sterilized or destroyed, and the plants, with the soil in which they had been grown, are burned.

The insectary rearing work with Eretmocerus provided a supply of adults for use in the earlier liberations, though this method was abandoned later. A considerable number of orange seedlings were heavily infested with the blackfly, and the parasites confined upon them when the fly had attained the second larval stage, though a varying number of other stages were also present. The cages used

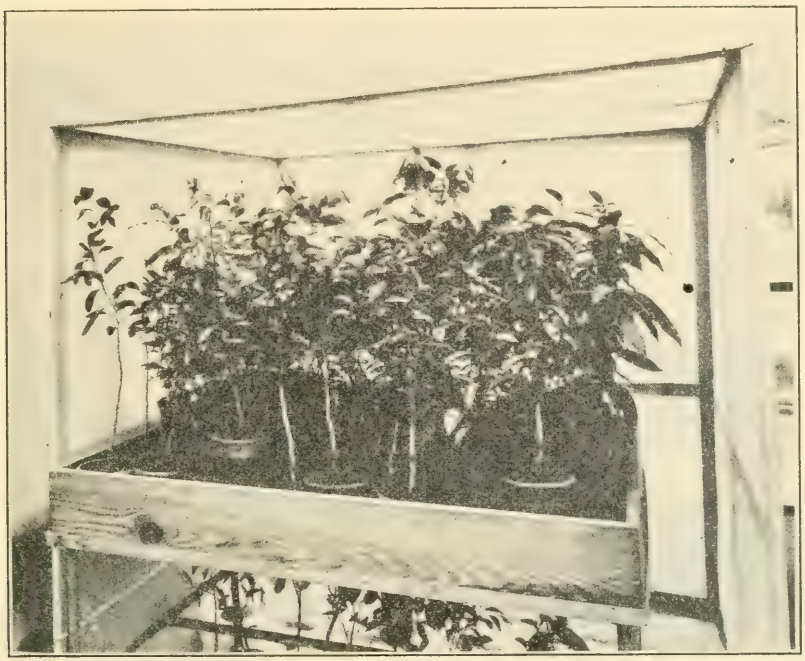

FIGURE 18.—Parasite emergence cage, with one cloth side removed. The infested plants shown are those which were grown in Wardian cages for six months while en route to Malaya and return. (Photo by Cuban Agricultural Experiment Station)

were of cloth and transparent cellulose paper, as illustrated in Figure 19, and from 20 to 50 parasite females were placed in each. Reproduction took place very satisfactorily under these conditions, and on each plant several thousand parasite progeny could develop. These were collected in vials and taken to the field, where they were placed in similar cages upon infested branches or liberated directly. The former is the more effective as it keeps the colony concentrated during the first generation.

In the later colonization work it was found to be much more satisfactory to collect the parasite adults in the field rather than to rear them in the insectary, and this involved considerably less work for a corresponding number of parasites. In any well-established colony in the field as many as 50 adults may be found upon a single leaf, and

this abundance permits each collector to secure several thousand per day. In making these field collections, as well as those from the plants and cages in the insectary, a suction bulb arrangement upon the collecting vials greatly facilitates rapid handling.

In the distribution of the parasites to localities too far distant for the forwarding of adults, the shipment of infested leaves from well-parasitized host colonies is the more practicable method. The leaves are collected when the blackfly is largely in the pupal stage and the parasites consequently nearly ready to emerge. The ordinary mailing tubes are satisfactory for shipping. Material collected in this way and kept under moderately humid conditions will yield parasites for a period of 10 to 15 days after collection.

FIGURE 19.—Bags of transparent cellulose paper and cloth, over infested citrus seedlings, used for rearing parasites and predators in the insectary and for field colonization. (Photo by Cuban Agricultural Experiment Station)

SUMMARY

The citrus blackfly (*Aleurocanthus woglumi*) occurs generally in all regions of tropical Asia, having been found in the Philippine Islands, southern China, French Indo-China, Siam, Malaya, the Dutch East Indies, Burma, India, and Ceylon. In the New World it was first discovered in Jamaica in 1913, and the infestation has now spread to Cuba, Haiti, Panama, Costa Rica, and the Bahama Islands.

In the Far East the species can be found only rarely upon plants other than citrus, and is of very minor importance upon this host, whereas in Central America and the West Indies a large variety of other plants is attacked, those most seriously affected being the Philippine mango and coffee.

In the development of the fly the dominant natural influences are humidity and rainfall. Increase is very rapid during the rainy season and a marked decline occurs during periods of dry weather.

The meteorological conditions in the citrus-producing sections of the United States indicate that the blackfly may become a major pest in Florida and the Gulf States if established there, but would be unable to withstand the adverse conditions prevailing in California.

The status of the blackfly as of no economic importance in the Far East is due almost exclusively to the mortality effected by the natural enemies. Of these there were found 6 species of parasitic chalcidoid Hymenoptera (*Encarsia merceti*, *Eretmocerus serius*, *Prospaltella divergens*, *P. smithi*, and *Prospaltella* spp.); 5 coleopterous predators (the nitidulid *Cybocephalus* sp. and the coccinellids *Cryptognatha* sp., *Scymnus smithianus*, *Scymnus* sp. near *pallidicollis*, and *Scymnus* sp.); 2 dipterous predators (*Acletoxenus indica* and *Acletoxenus* sp.); 1 neuropterous predator (*Chrysopa* sp.); and 1 lepidopterous predator (*Cryptoblabes gnidiella*).

The internal parasites are responsible for an average mortality of 54 to 67 per cent in each generation in the field. In all sections approximately 50 per cent of the parasites are destroyed in the late larval or pupal stage by hyperparasites of the genus Ablerus.

Of the parasites listed above, *Eretmocerus serius* has been imported into Cuba and successfully established. Commercial control has been effected in most of the groves in which the early liberations were made, this being normally effected within 8 to 12 months from the first liberation. The extent of parasitization in these groves at the time of control has ranged from 72 to 78 per cent.

Colonies of Eretmocerus have been liberated in many groves in all of the provinces of Cuba, and have also been sent to the Canal Zone, the Bahamas, and Haiti.

Eretmocerus is an external parasite in its first two larval stages and internal in the final stages. Oviposition takes place preferably beneath the second larval stage of the host, though any stage may be attacked. Two generations are developed upon each one of the host.

Among the coccinellid predators, *Cryptognatha* sp. and *Scymnus smithianus* are now established in Cuba. Cryptognatha has fully controlled a heavy blackfly infestation in at least one grove, but its effectiveness is very uncertain. This species can be only an aid to Eretmocerus in the initial subjugation of the host infestation, and can not be relied upon for permanent control. *Scymnus smithianus* is apparently not adapted to Cuban conditions, as reproduction is largely suspended during the summer months.

In the New World no native parasites have been found to attack the blackfly, though a number of coccinellid beetles prey upon it.

Fungous diseases, primarily those produced by forms in the genera Aschersonia and Aegerita, at times effect a fairly high mortality upon the larval and pupal stages of the blackfly in the West Indies. These occur in Malaya also, though only rarely upon *Aleurocanthus woglumi*, in spite of the apparently more favorable climatic conditions for development.

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WASHINGTON, D. C.

THE FRACTIONATION, COMPOSITION, AND HYPOTHETICAL CONSTITUTION OF CERTAIN COLLOIDS DERIVED FROM THE GREAT SOIL GROUPS

By IRVIN C. BROWN, *Associate Chemist*, and HORACE G. BYERS, *Principal Chemist, Division of Soil Chemistry and Physics, Soil Investigations, Bureau of Chemistry and Soils*

CONTENTS

	Page		Page
Introduction	1	The difficultly extractable colloid	26
Preliminary study	3	Water vapor absorption of the difficultly extractable colloid	30
Description of samples	5	The Pasteur-Chamberland filtrate	31
Method of extraction of the colloid fractions	7	General discussion	33
Methods and results of examination of the fractions	9	Summary	40
Water vapor absorption and heat of wetting	21	Literature cited	42

INTRODUCTION

In the intensive investigations of soil colloids, which have engaged the attention of soil chemists in recent years, it has been customary to regard the material separated from a given soil by dispersion in water as essentially homogeneous. It does not follow, however, that it has been considered a chemical unit. The material extracted has usually been considered as fairly representative of the total colloid, although a complete separation of the colloid is never obtained. In the work by Bradfield (*9*)[1] the material not separated from a suspension of Putnam silt loam subsoil after 30 days' standing was separated into three fractions by means of a centrifuge, and two of these fractions were analyzed and the difference noted and commented upon. In the work of Gile et al. (*15*) attempts were made to fractionate the colloid material of several soils by repeated dispersion and separation by the centrifuge. The absorptive capacities of these fractions of the total "extractable" colloid were determined and though differences were noted, the conclusion reached was that "on the whole the different fractions were similar in absorptive capacity to the first sample extracted." In the work reported by Robinson and Holmes (*28*) the chemical analyses of the same fractions are given, and again, though differences were noted, the conclusion was reached that there is comparatively little variation in the composition of the colloidal material extracted from the same soil. In the same bulletin Robinson and Holmes reported the result of their efforts to fractionate soil colloids by precipitation and by freezing and thawing. The results were negative. Also, in the bulletin by Gile et al., previously cited, the authors concluded (*15, p. 38*):

[1] Italic numbers in parentheses refer to Literature Cited, p. 42.

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The adsorptive capacity of a small sample of extracted colloidal material differs by about 10 per cent from the adsorptive capacity of all the colloidal material which is extractable by the methods employed. However, the colloidal material which can not be extracted has, in many soils, a much lower adsorptive capacity than that which is extractable.

Iwanow (*18*) separated the colloidal material from the sodium-saturated chernozem soils and after redispersion filtered the suspension through a Birkfeld filter. After evaporation, ignition, and leaching with water, he analyzed the residue and compared the values so obtained with the analyses of the colloid retained by the filter. The results obtained showed striking differences in the colloid fractions, but the results are not very significant since the material passing the Birkfeld filter contains not only the very small colloid particles but also the ash of the organic material and soluble inorganic material. The fine material estimated to be 0.1 micron in diameter constituted about 4 per cent of the extracted colloid.

Denison (*14*) attempted the fractionation of the colloid from certain horizons of three soil types, a Durham sandy loam and a Cecil sandy clay loam from Georgia, and a Cecil clay loam from North Carolina. He confined his attention to portions of the C horizon, since previous work on A and B horizons had indicated the existence of no marked variations in the colloid fractions obtained by successive dispersions. His method of extraction is described by him as follows: (*14, p. 476–477*):

The first fraction was made as follows: A 10 to 20 g [2] sample of soil material was moistened with water and the mass worked to a somewhat plastic consistency by rubbing the particles between the fingers. A small quantity of water made alkaline with ammonia was then added and after settling for a few minutes the suspension was decanted into a 500 c c glass cylinder. The settled portion was rubbed between the fingers as before, and the process repeated until the cylinder was filled. The suspension was now allowed to settle until microscopic examination showed that the suspension to a certain depth was practically free of particles more than 1 micron in diameter. The colloidal solution was then drawn off to this depth and evaporated to dryness. The second fraction was prepared in a similar manner except that the silty material obtained by removal of the greater part of the colloid (explained under Methods) was employed instead of the soil material. In preparing this second fraction about 50 g of material were dispersed in 3 liters of water (alkaline to phenolpthalein) contained in a beaker and the colloidal solution drawn off when nearly all particles more than 1 micron in diameter had settled. The quantities of colloid obtained in all cases were very small, averaging not more than 0.5 g.

The results obtained from such small fractions were somewhat inconclusive, but were so remarkable as to warrant a more extended investigation. The present investigation was begun for the purpose of extending the work of Denison, and large samples of the soils from the same localities were obtained by one of the authors. In the interval before securing these samples a preliminary examination of the Davidson clay loam subsoil was made, and the results indicated the desirability of an alteration of the method to be employed. As the data were accumulated it became apparent that they threw much light upon the question of colloid constitution and soil origin, and they have therefore been made the basis of a brief general discussion of these topics.

[2] g is the abbreviation for gram or grams.

PRELIMINARY STUDY

A preliminary study was made on the B_1 horizon of a sample of Davidson clay loam collected 9 miles north of Greensboro, N. C., by R. C. Jurney, of the division of soil survey. It is the same sample on which complete profile data are reported by Middleton (*22*). The silica-sesquioxide ratio of the colloid of the B_1 horizon is 1.50. The colloid content by mechanical analysis is 64.8 per cent.

The fractionation of this soil was effected as follows: One kilogram of the air-dried soil was well shaken in 18 liters of N/200 sodium oxalate solution and poured through a 300-mesh sieve. The resulting suspension had a pH of 8.4. After 20 hours the suspended portion was syphoned off and filtered. The operation was repeated 15 times with the filtrate as a dispersing agent, until the supernatant liquid was clear after standing 20 hours. The suspended particles were 1 micron or less in diameter. The residual material was then dispersed in the same manner as later described for the size fractionation (step 3) and all the colloid obtained that could be centrifuged off after eight dispersions with N/200 sodium oxalate. The residual material was then dispersed and centrifuged eight times with N/400 sodium hydroxide solution.

The residual material was again dispersed, using N/200 sodium hydroxide solution as a dispersing agent. This operation was repeated eight times. The total colloid obtained in the four fractions was 441.4 g when dried on the steam bath. Examination of the material which failed to pass the 300-mesh sieve, as well as the silt and clay fractions of the repeatedly dispersed material, revealed the presence of much undispersed material.

A recapitulation of the method of extraction and the analyses of the four fractions of colloid are given in Table 1.

TABLE 1.—*Chemical composition of successive fractions of colloids from Davidson clay loam, B_1 horizon*

[Depth, 9 to 36 inches]

Steps in the fractionation of the colloid	Method of extraction	Fraction of whole soil	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio: $\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	Molecular ratio: $\frac{SiO_2}{Fe_2O_3}$	Molecular ratio: $\frac{SiO_2}{Al_2O_3}$	Molecular ratio: $\frac{Fe_2O_3}{Al_2O_3}$	Molecular ratio: $\frac{SiO_2}{\text{Total bases}}$
			Per cent	*Per cent*	*Per cent*					
1	Colloid (<1μ) separated by subsidence (15 times)	1.68 per cent	37.89	14.69	31.87	1.57				
		Duplicate	37.87	14.82	31.38	1.57				
		Mean	37.88	14.76	31.63	1.57	6.80	2.03	0.298	27.5
2	<1μ separated by centrifuging 8 times.	37.50 per cent	36.30	15.79	31.68	1.47				
		Duplicate	36.38	15.85	31.63	1.47				
		Mean	36.34	15.82	31.66	1.47	6.09	1.95	.320	33.0
3	Continued centrifuging residue from 2, 8 times (<1μ=upper limit of size).	3.62 per cent	36.80	14.74	29.52	1.60				
		Duplicate	36.75	14.70	29.54	1.60				
		Mean	36.77	14.72	29.53	1.60	6.62	2.11	.319	16.1
4	Continued centrifuging residue from 3, 8 times (<1μ=upper limit of size).	1.66 per cent	37.07	12.79	28.60	1.70				
		Duplicate	37.08	12.54	28.71	1.70				
		Mean	37.08	12.66	28.65	1.70	7.74	2.19	.283	18.3

Steps in the fractionation of the colloid	Method of extraction	Fraction of whole soil	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Organic matter	Combined water
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per ceent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	Colloid (<1μ) separated by subsidence (15 times).	1.68 per cent	0.62	0.16	0.54	0.00	0.67	0.05	0.07	0.90	12.17
		Duplicate	.60	.08	.50	.00	.76	.07	.09	1.04	12.20
		Mean	.61	.12	.52	.00	.71	.06	.08	.97	12.18
2	<1μ separated by centrifuging 8 times.	37.50 per cent	.47	.14	.41	.19	.80	.05	.11	1.36	12.30
		Duplicate	.47	.10	.43	.14	.82	.05	.12	1.17	12.48
		Mean	.47	.12	.42	.16	.81	.05	.12	1.27	12.39
3	Continued centrifuging residue from 2, 8 times (<1μ=upper limit of size).	3.62 per cent	.96	.49	.65	.17	.70	.04	.24	4.14	10.50
		Duplicate	.98	.49	.64	.12	.70	.04	.24	3.94	10.66
		Mean	.97	.49	.65	.15	.70	.04	.24	4.04	10.58
4	Continued centrifuging residue from 3, 8 times (<1μ=upper limit of size).	1.66 per cent	.95	.12	.94	.00	.71	.09	.21	5.59	12.15
		Duplicate	.90	.10	.78	.00	.71	.11	.17	5.53	12.15
		Mean	.93	.11	.86	.00	.71	.10	.19	5.56	12.15

An examination of the data of Table 1 reveals the fact that no serious segregation of colloid fractions of varying composition was produced.

It will be observed that the first fraction obtained by subsidence is slightly richer in silica and poorer in iron oxide than is the fraction which represents the bulk of the extractable colloid. Its silica-sesquioxide ratio is therefore somewhat higher. The more difficultly extractable colloid fractions also have a somewhat higher silica-sesquioxide ratio. The third and fourth fractions are richer in total bases and have increasingly higher ignition losses than the second fractions. It might be inferred legitimately, therefore, that increasing amounts of partly hydrolyzed or wholly undecomposed minerals were being brought into these fractions. This is in agreement with the results obtained by Robinson and Holmes (*28*). Any far-reaching

inferences are, however, not warranted and the general conclusion was reached that more satisfactory results might be obtained by attempting the fractionation on the basis of size distribution, the results of which effort form the body of this bulletin. The size separation of the colloidal material was made not only on the colloidal material, as ordinarily separated from soils, but was also carried out, as later described, on the colloid material ordinarily described as "unextracted" colloid (*15, p. 19*).

DESCRIPTION OF SAMPLES

The soils investigated in this study were selected in the first instance to obtain colloids that were presumably mixtures of materials and that might therefore be expected to furnish fractions of diverse composition. They are also soils of which the laboratory possesses complete profile samples upon which considerable work had already been done. As the work developed it seemed desirable to include two samples of less weathered soils which, on the basis of information at hand, were not to be expected to show widely different fractions. The samples chosen and their descriptions are tabulated in Table 2.

TABLE 2.—*Description and location of soil samples*

Laboratory No.	Soil type	Depth	Horizon	Description	Parent material	Location
		Inches				
4575	Amarillo silty clay loam.	10–20	2	Rich-brown color with faint tint of red.	High plains deposits.	Nash, Tex.
191	Marshall silt loam	0–14	1	Dark-brown color, moderately compact but friable and easily crumbled, plastic, and sticky when wet.	Loess	Maynard, Nebr.
4447	Becket silt loam	13–24	B_2	Yellowish-brown, grading to pale yellowish-brown color, friable.	Glacial till from crystalline calcareous rocks.	Washington, Mass.
6263	Durham sandy loam.	90–102	C_3	Very light gray slightly decomposed rock.	Granite	Stone Mountain, Ga.
4440	Davidson clay loam.	9–36	B_1	Reddish heavy brittle clay.	Diorite	Greensboro, N. C.
6278	Cecil clay	36–72	B_2	Red stiff brittle clay	Gneiss	Rutherfordton, N. C.
6274	Cecil sandy clay loam.	180–196	C_4	Grayish-brown disintegrated rock.	Mica schist	Stone Mountain, De Kalb County, Ga.
6281	Cecil clay loam	112+	C_3	Gray soft disintegrated rock.	Gneiss	Rutherfordton, N. C.

The mechanical and chemical analyses of the samples are given in Tables 3 and 4, respectively.

TABLE 3.—*Mechanical composition of soil samples*

Sample No.	Soil type	Depth	Horizon	Fine gravel 2–1 mm	Coarse sand 1–0.5 mm	Medium sand 0.5–0.25 mm	Fine sand 0.25–0.1 mm
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*
4575	Amarillo silty clay loam	10–20	2	0.0	0.1	0.2	1.9
191	Marshall silt loam	0–14	1	.0	.1	.1	.2
4447	Becket silt loam	13–24	B_2	3.1	5.5	6.9	21.2
6263	Durham sandy loam	90–102	C_3	9.7	16.1	10.3	15.4
4440	Davidson clay loam	9–36	B_1	.1	.7	.9	5.4
6278	Cecil clay loam	36–72	B_2	1.5	14.9	14.6	26.8
6274	Cecil sandy clay loam	180–196	C_4	6.1	17.2	14.0	32.8
6281	Cecil clay loam	112+	C_3	9.8	28.0	15.4	19.8

Sample No.	Soil type	Depth	Horizon	Very fine sand 0.1–0.05 mm	Silt 0.05–0.005 mm	Clay <0.005 mm	Inorganic colloid <0.002 mm	Loss on treatment with H_2O_2
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
4575	Amarillo silty clay loam	10–20	2	8.3	41.0	47.4	42.8	1.1
191	Marshall silt loam	0–14	1	2.0	62.2	31.2	27.8	4.3
4447	Becket silt loam	13–24	B_2	18.4	30.2	9.0	5.5	5.6
6263	Durham sandy loam	90–102	C_3	9.2	9.5	29.7	28.4	.0
4440	Davidson clay loam	9–36	B_1	8.9	22.3	60.4	54.0	1.3
6278	Cecil clay loam	36–72	B_2	15.4	18.5	8.3	6.3	.0
6274	Cecil sandy clay loam	180–196	C_4	17.7	9.1	3.0	1.7	.0
6281	Cecil clay loam	112+	C_3	8.7	10.3	8.0	6.2	.0

TABLE 4.—*Chemical composition of soil samples*

Sample No.	Soil type	Depth	Horizon	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio $\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	MgO	CaO	K_2O
		Inches		*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*
4575	Amarillo silty clay loam	10–20	2	70.48	4.40	13.88	7.14	1.35	0.97	2.56
191	Marshall silt loam	0–14	1	72.06	3.66	11.18	9.78	.66	.90	2.66
4447	Becket silt loam	13–24	B_2	72.67	3.58	10.32	11.94	.41	.62	3.45
6263	Durham sandy loam	90–102	C_3	70.51	1.02	17.46	6.61	.18	.24	6.22
4440	Davidson clay loam	9–36	B_1	52.70	10.62	22.87	3.01	.40	.51	.45
6278	Cecil clay loam	180–196	C_4	61.51	7.82	19.25	4.30	1.84	.22	3.10
6274	Cecil sandy clay loam	9–36	B_2	49.24	9.65	26.14	2.58	1.49	.22	2.44
6281	Cecil clay loam	112+	C_3	54.18	7.40	23.90	3.19	1.64	.57	2.41

Sample No.	Soil type	Depth	Horizon	Na_2O	TiO_2	MnO	P_2O_5	Ignition loss	N	SO_3	pH
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
4575	Amarillo silty clay loam	10–20	2	1.01	0.71	0.09	0.09	4.97	0.08	0.07	7.8
191	Marshall silt loam	0–14	1	1.02	.67	.05	.21	6.94	.23	.12	-----
4447	Becket silt loam	13–24	B_2	.67	.70	.02	.08	7.27	.09	.14	4.1
6263	Durham sandy loam	90–102	C_3	.52	.08	.02	.32	3.85	-----	-----	5.1
4440	Davidson clay loam	9–36	B_1	.00	1.39	.07	.12	10.55	.02	.12	5.1
6278	Cecil clay loam	180–196	C_4	.21	1.04	.17	.12	5.27	-----	.05	-----
6274	Cecil sandy clay loam	9–36	B_2	.05	1.79	.12	.29	9.40	-----	.07	-----
6281	Cecil clay loam	112+	C_3	.24	1.26	.11	.49	8.55	-----	.07	-----

METHOD OF EXTRACTION OF THE COLLOID FRACTIONS

The colloid was separated from the soils and fractionated by the use of two Sharples supercentrifuges (*6*). The larger of these had a maximum safe operating speed of 17,000 revolutions per minute and a bowl diameter of 4 inches, therefore developing at this speed 17,000 gravity. The smaller centrifuge had a maximum operating speed of 40,000 revolutions per minute, a bowl diameter of 2 inches, and developed 40,000 gravity.

One-half to 2 kg of soil were dispersed with 10 to 15 liters of water in a stirring apparatus described by Holmes and Edgington. (*17*), to which was added just sufficient ammonium hydroxide to render the suspension faintly alkaline. The liquid was allowed to stand sufficiently long for the sands to settle and this supernatant liquid decanted through a 300-mesh sieve. This operation was repeated until a total of about 20 gallons of suspension was obtained.

The suspension of fine silt, clay, and colloid was then run through the larger centrifuge operating at 17,000 revolutions per minute and the liquid poured through at a rate of 1 liter per 35 seconds. The liquid was filtered through Pasteur-Chamberland filters. The material left in the centrifuge bowl was then redispersed by rubbing between the hands and by agitation in the stirring apparatus. The water used for this operation was obtained by filtration of the previously separated colloid. This operation of centrifuging and redispersing was continued from 5 to 10 times until the liquid from the centrifuge showed almost no colloid content, i. e., the liquid showed but faint opalescence.

The colloid so collected on the filters contained no significant number of particles of a diameter greater than 0.3 micron, as shown by examination with an ultra microscope. The residue of colloid coarser than 0.3 micron was separated from the fine silt and clay by exactly the same treatment except that the rate of flow through the centrifuge was increased to 1 liter per 17 seconds. This part of the colloid was separated by filtration. Examination of this fraction with the ultra microscope revealed the presence of no significant number of particles larger than 1 micron and surprisingly few of less than 0.3 micron.

The noncolloidal residue was then separated into two fractions by redispersion and certrifuging at a rate of flow of 1 liter per 4 seconds, with a centrifuge rate of 7,000 revolutions per minute. This operation had to be repeated several times in order to effect complete separation into fractions 1 to 5 microns and 5 to 50 microns, respectively. The clay fraction was collected by filtration; the fine silt remained in the bowl of the centrifuge.

In order to separate the fraction of colloid of a 0.3 micron and smaller sizes into two fractions, the small supercentrifuge was employed. This colloidal material was again dispersed and run through the centrifuge at a rate of 40,000 revolutions per minute and a rate of flow of 1 liter per two minutes. The centrifugate contained from 25 to 60 per cent of the colloid so treated, and by the ultra microscope the particles so obtained were exceedingly minute. This fraction is estimated to contain no significant number of particles greater than 0.1 micron.

The same water was used throughout the series of separations and at the end had a pH value ranging from 8.3 to 8.7.

The method of separation and its results are recapitulated in Table 5.

TABLE 5.—*Fraction sizes of particles at various steps in the process of extracting the colloids*

Step	Centrifuge rate	Gravity	Rate of flow per liter	Particle size
	Revolutions per minute		*Seconds*	
1	40,000	40,000	120	<0.1μ (colloid).
2	17,000	17,000	37	<0.3μ (colloid).
3	17,000	17,000	16	0.3μ to 1.0μ (colloid).
4	7,000	2,800	4	1μ to 5μ (clay).
5				5μ to 50μ (silt).

It is to be emphasized that, in order to obtain the size separation shown in Table 5, each operation was repeated from 5 to 10 times, until the centrifugates obtained showed that no further separation would be effective in materially increasing the quantities of the successively smaller fractions. Considerable differences in the rapidity with which the operations were completed were noted in the different soils. The quantities of colloid so obtained were always smaller than those indicated by either the pipette method of mechanical analysis (*25*) or the water vapor absorption method (*26*), except in the case of the C_3 horizon of the Cecil clay loam, where the amount extracted is essentially the same as the percentage indicated by mechanical analyses. It is recognized that both methods are approximations and that the pipette method includes particles of the sizes 1 to 2 microns. Nevertheless, the differences between the amounts obtained and those indicated by the mechanical analysis (Table 3) were sufficiently wide to encourage attempts at further extraction. It has been shown by Olmstead, Alexander, and Middleton (*25*) that increased dispersion may be effected by using sodium hydroxide at pH values well above 7. Three of the samples under investigation were therefore selected, and the combined silt and clay fractions were redispersed, using pH values of 10.5 to 11.0. The quantities of colloid ($<1\mu$) extracted by the two methods are given in Table 6.

TABLE 6.—*Quantities of colloid extracted from the soil samples by using two methods*

Sample No.	Soil type	Depth	Colloid, percentage of whole soil, extracted by water and ammonia. pH 7–8.7	Colloid, percentage of whole soil, extracted by NaOH from silt and clay fraction
		Inches		
4575	Amarillo silty clay loam	10–20	31.7	1.1
191	Marshall silt loam	0–14	21.3	
4447	Becket silt loam	13–24	3.1	1.2
6263	Durham sandy loam	90–102	23.4	
4440	Davidson clay loam	9–36	34.4	.8
6278	Cecil clay loam	36–72	4.9	
6274	Cecil sandy clay loam	180–196	1.5	
6281	Cecil clay loam	112+	8.1	

After extraction with sodium hydroxide the silt and clay fractions were examined by W. H. Fry and found to contain very small quantities of residual colloids. It will be observed by comparison with the data in Table 3 that there is a considerable margin between the total colloid extracted and the sum of the colloid and organic matter by mechanical analysis. A part of the discrepancy is accounted for by the fact that the concretionary colloid remaining with the sands on the 300-mesh screen is not included in the samples examined. A part is to be ascribed to the fact that the colloid by mechanical analysis includes the particles up to 2 microns. It is also to be kept in mind that unavoidable losses occur in extraction operations. On the whole, the fractions of the total colloid included in the analyses represent an unusually large part of the total colloids present in the soils.

METHODS AND RESULTS OF THE EXAMINATION OF THE FRACTIONS

The soil fractions, obtained as described, of the eight soil horizons from seven different soils were examined by subjecting them to fusion analysis, using the methods described by Robinson (*27*). The water vapor absorption over 3.3 per cent sulphuric acid, over 30 per cent sulphuric acid, and the heat of wetting were determined as described in previous publications of this bureau (*1, 21, 26*). The data obtained are given in Tables 7 to 16. Each determination was made in duplicate and the individual determinations and their mean values are recorded.

The sequence of the tables is not that in which the data were obtained, but the tables are arranged in the order given for convenience of discussion and because of relationships brought out in the general discussion.

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TABLE 7.—*Chemical composition of fractions of soil colloids, clay, and silt from a southern chernozem, Amarillo silty clay loam, horizon 2, 10–20 inches depth*

Fraction of whole soil (per cent)	Size	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio $\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	Molecular ratio $\frac{SiO_2}{Fe_2O_3}$	Molecular ratio $\frac{SiO_2}{Al_2O_3}$	Molecular ratio $\frac{Fe_2O_3}{Al_2O_3}$	Molecular ratio $\frac{SiO_2}{\text{Total bases}}$
		Per cent	*Per cent*	*Per cent*					
19.1	<0.1μ	50.95	8.50	22.95	3.04				
	Duplicate	50.86	8.61	22.87	3.03				
	Mean	50.91	8.56	22.91	3.04	15.8	3.76	0.238	6.65
6.2	0.1μ–0.3μ	49.60	8.65	22.27	3.03				
	Duplicate	49.65	8.70	22.23	3.03				
	Mean	49.63	8.67	22.25	3.03	15.4	3.77	.248	6.53
6.4	0.3μ–1μ	51.05	7.41	22.13	3.22				
	Duplicate	51.00	7.52	22.05	3.22				
	Mean	51.03	7.46	22.09	3.22	18.2	3.95	.214	6.70
4.7	1μ–5μ	57.98	6.16	16.54	4.80				
	Duplicate	58.10	6.12	16.50	4.81				
	Mean	58.04	6.14	16.52	4.81	25.1	5.94	.237	8.70
12.7	5μ–50μ	76.00	2.62	10.93	10.22				
	Duplicate	75.98	2.61	10.85	10.26				
	Mean	75.99	2.62	10.89	10.24	76.8	11.83	.155	5.72

Fraction of whole soil (per cent)	Size	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Organic matter	Combined water
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
19.1	<0.1μ	2.90	1.72	2.22	0.14	0.46	0.10	0.09	1.67	8.42
	Duplicate	2.82	1.66	2.17	.18	.46	.10	.09	1.57	8.48
	Mean	2.86	1.69	2.20	.16	.46	.10	.09	1.62	8.45
6.2	0.1μ–0.3μ	2.69	1.30	2.98	.28	1.00	.12	.18	3.70	7.16
	Duplicate	2.69	1.30	2.98	.24	1.00	.12	.17	3.81	7.08
	Mean	2.69	1.30	2.98	.26	1.00	.12	.18	3.76	7.12
6.4	0.3μ–1μ	2.65	1.36	2.92	.34	.89	.16	.17	4.27	6.97
	Duplicate	2.66	1.42	2.92	.28	.89	.16	.16	4.17	7.13
	Mean	2.66	1.39	2.92	.31	.89	.16	.17	4.22	7.05
4.7	1μ–5μ	1.69	1.16	3.27	.82	1.25	.20	.26	6.05	4.68
	Duplicate	1.60	1.18	3.29	.93	1.21	.19	.24	6.08	4.73
	Mean	1.65	1.17	3.28	.87	1.23	.20	.25	6.07	4.70
12.7	5μ–50μ	1.25	.46	2.85	1.80	1.01	.05	.11	2.94	.46
	Duplicate	1.22	.40	2.84	1.73	1.00	.05	.10	2.79	.61
	Mean	1.24	.43	2.85	1.77	1.00	.05	.10	2.87	.54

The data presented in Table 7 show the chemical composition of the fractions of the second layer of Amarillo silty clay loam. The material used is a part of the same profile sample reported on by Anderson and Byers (*3*). It is a representative of the southern chernozems, and the whole profile is characterized by marked uniformity of the colloid, in particular of the first three horizons, in which the silica-sesquioxide ratio is 3.10, 3.09, and 3.13, respectively. The colloid content (< 0.002 mm), as shown by mechanical analysis, is 23.9 per cent in the upper layer and 42.8 per cent in the stratum examined. In the first three fractions represented in Table 7, 31.7 per cent was extracted. The largest fraction, 19.1 per cent, consists of the particles of smallest size, i. e., smaller than 0.1 micron.

The chemical analyses of the fractions reveals a very striking similarity between 0.1-micron and 0.3-micron fractions. The silica-sesquioxide ratios are identical. The chief difference is in the organic matter. The mean value of the organic matter is 4.02 per cent, and the smaller value in the finest fraction indicates a low degree of decomposition of the organic matter, a fact quite in harmony with the low rainfall of the region in which this soil occurs. There is a moderate

difference in the combined water of the finer colloid fractions, which is clearly significant of a higher degree of hydration of the finest particles. Indeed there are no marked differences in the three fractions of colloid, except that in the fraction 0.3 to 1 micron the slightly increased silica-sesquioxide ratio, the silica-alumina ratio, and the silica-iron oxide ratio all point to the presence of quartz particles in colloidal form, especially when considered in the light of the enormous increase in these ratios in the clay and silt fractions. That quartz is present in the clay fraction is established by petrographic microscopic inspection by W. H. Fry.

In this colloid there is some indication of increase in the iron-oxide content of the finer fractions of the colloid, as indicated by the silica-iron oxide ratio, though the alteration is not large. The change of ratio of iron oxide to the alumina also indicates a slight tendency of the iron oxide to drift to the finer particles.

All these ratios, together with the constancy of the molecular ratio of the silica to the sum of the bases present in the colloid fractions, may be taken to indicate in this colloid the presence of an acid complex of constant composition. This conclusion is in harmony with the data on the colloids of the whole profile presented by Byers and Anderson (*10*).

The material used for the data presented in Table 8 is from the surface layer of the soil profile of Marshall silt loam, on which data are reported by Robinson and Holmes (*28*) and also by Byers and Anderson (*10*). It is a northern prairie soil developed under much the same conditions as the Amarillo soil but with a sufficiently high rainfall to prevent the accumulation of a layer of calcium carbonate. It is to be noted that this is a surface soil material, whereas the Amarillo is a lower stratum. With this in mind the similarity of the two colloids is striking. Although the Amarillo soil has a lower total silica content than the Marshall, the colloid of the Amarillo is about 5 per cent higher. This fact, coupled with the small but definite increase of the silica-sesquioxide ratio with increasing particle size, may be taken to indicate that the process of removal of silica from the finer fractions has been operative as the process of weathering has developed. However, leaching has not been extensive, though it is sufficient to prevent calcium carbonate accumulation.

In both the Amarillo and Marshall soils, the silica-base ratio [3] does not alter sharply until the clay-size particles, 1 to 5 microns, are reached, and it is of essentially the same order of magnitude. This may be taken to indicate the same type of acid complex in both soils. This conclusion is also in harmony with the general similarity of the silica-iron oxide and silica-alumina ratios. The meaning of the decrease of the silica-base ratio in the 0.3-micron fraction of the colloid is not clear.

In the Marshall soil, there is a smaller quantity of organic matter in the smaller fractions of the colloid and an increased combined water content. These facts again point, as in the Amarillo soil, to greater hydration of the finer fractions of inorganic colloid and to a less degree of decomposition of the organic material.

In the Marshall colloid fractions there is a small but definite decrease in the relative iron-oxide content of the coarser particles,

[3] It is to be observed that the silica-base ratio is not quite valid in detailed consideration except in Tables 7 and 8, since the other colloids were extracted, using a small quantity of ammonia, thus removing a portion of exchangeable bases.

which becomes marked when the clay size is reached. This is, as in the case of the Amarillo soil, to be expected as indicating a more extensive hydrolytic decomposition of the finer particles.

TABLE 8.—*Chemical composition of fractions of soil colloids, clay, and silt from a northern prairie soil, Marshall silt loam, 0–14 inches depth*

Fraction of whole soil	Size	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio $\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$
Per cent		*Per cent*	*Per cent*	*Per cent*					
10.0	<0.1μ	45.10	9.07	22.20	2.73				
	Duplicate	45.05	9.07	22.10	2.74				
	Mean	45.08	9.07	22.15	2.74	13.2	3.44	0.261	6.76
4.5	0.1μ–0.3μ	44.30	8.76	20.70	2.85				
	Duplicate	44.30	8.91	20.69	2.85				
	Mean	44.30	8.83	20.70	2.85	13.4	3.62	.270	6.23
6.8	0.3μ–1μ	44.40	8.54	19.62	3.00				
	Duplicate	44.50	8.57	19.62	3.00				
	Mean	44.45	8.56	19.62	3.00	13.8	3.83	.278	6.61
5.3	1μ–5μ	51.20	7.00	15.99	4.24				
	Duplicate	51.20	6.89	16.01	4.25				
	Mean	51.20	6.94	16.00	4.25	19.6	5.42	.283	8.58
27.2	5μ–50μ	79.00	2.00	9.44	12.50				
	Duplicate	79.20	1.97	9.55	12.45				
	Mean	79.10	1.99	9.49	12.47	104.5	14.11	.135	7.19

Fraction of whole soil	Size	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Organic matter	Combined water
Per cent		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
10.0	<0.1μ	2.28	1.76	1.89	0.16	0.46	0.29	0.22	7.69	8.84
	Duplicate	2.29	1.72	1.96	.11	.44	.28	.21	7.58	9.12
	Mean	2.29	1.74	1.92	.14	.45	.29	.22	7.64	8.98
4.5	0.1μ–0.3μ	2.14	1.92	2.61	.18	.73	.35	.31	10.34	7.35
	Duplicate	2.21	1.98	2.50	.18	.75	.35	.30	10.25	7.40
	Mean	2.18	1.95	2.55	.18	.74	.35	.31	10.29	7.38
6.8	0.3μ–1μ	2.17	1.49	2.57	.17	.80	.33	.34	11.75	7.49
	Duplicate	2.26	1.58	2.52	.16	.78	.33	.33	11.77	7.28
	Mean	2.22	1.53	2.55	.17	.79	.33	.34	11.76	7.39
5.3	1μ–5μ	1.74	1.18	2.87	.33	.99	.23	.43	12.10	5.41
	Duplicate	1.68	1.14	2.94	.35	.96	.20	.44	12.01	5.54
	Mean	1.71	1.16	2.90	.34	.98	.22	.44	12.06	5.48
27.2	5μ–50μ	.55	.74	2.51	1.51	.74	.03	.14	2.03	1.15
	Duplicate	.55	.70	2.46	1.47	.73	.03	.10	1.85	1.40
	Mean	.55	.72	2.49	1.49	.74	.03	.12	1.94	1.27

The data of Table 10 show the composition of the B_2 horizon of Becket silt loam. The sample examined is a part of the profile sample reported on by Anderson and Byers (*3*). The B_1 horizon is a very thin highly ferruginous layer. The B_2 horizon was chosen for this study as representing a more nearly normal B horizon of the podzol type and because an abundance of the sample was available.

There are a number of striking contrasts between results obtained with the podzol B_2 and the subsurface soil colloid of the Amarillo soil (Table 7) and the surface soil colloid of the Marshall soil. (Table 8.) The silica content is less than half that of the soils mentioned and in the finest fraction (0.1 micron) is approximately one-third. This is in part due to the enormous content of organic matter, but even on the inorganic basis the relative quantities of the three cited constituents taken as 100 are as shown in Table 9 for the 0.1-micron fraction.

The variation among these three soils is obviously much more marked in the iron oxide content and is apparent for the alumina.

The wide differences in the character of the colloid are, of course, also indicated by the silica-sesquioxide ratio, the silica-iron oxide ratio, and the silica-alumina ratio.

TABLE 9.—*The relative silica, alumina, and iron-oxide content of the 0.1μ fraction of the Becket, Amarillo, and Marshall colloids*

Components	Becket	Amarillo	Marshall
Si_2O	32.63	61.80	60.23
Fe_2O_3	28.16	10.39	12.12
Al_2O_3	39.22	27.81	27.65

TABLE 10.—*Chemical composition of fractions of soil colloids, clay, and silt from a podzol, Becket silt loam, B_2 horizon, 10–20 inches depth*

Fraction of whole soil (per cent)	Size	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio: $\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	Molecular ratio: $\frac{SiO_2}{Fe_2O_3}$	Molecular ratio: $\frac{SiO_2}{Al_2O_3}$	Molecular ratio: $\frac{Fe_2O_3}{Al_2O_3}$	Molecular ratio: $\frac{SiO_2}{\text{Total bases}}$
		Per cent	*Per cent*	*Per cent*					
0.6	<0.1μ	15.78	13.67	18.95	0.97				
	Duplicate	15.78	13.57	18.96	.97				
	Mean	15.78	13.62	18.96	.97	3.08	1.41	0.458	3.60
0.8	0.1μ–0.3μ	22.23	11.89	20.99	1.32				
	Duplicate	22.27	11.89	21.00	1.32				
	Mean	22.25	11.89	21.00	1.32	4.96	1.79	.361	4.04
1.7	0.3μ–1μ	26.89	11.39	20.51	1.64				
	Duplicate	27.00	11.39	20.62	1.64				
	Mean	26.94	11.39	20.56	1.64	6.26	2.21	.352	5.75
1.9	1μ–5μ	28.50	11.55	20.42	1.73				
	Duplicate	28.50	11.64	20.46	1.73				
	Mean	28.50	11.60	20.44	1.73	6.52	2.36	.362	5.44
7.1	5μ–50μ	50.38	7.18	18.77	3.65				
	Duplicate	50.22	7.21	18.92	3.64				
	Mean	50.30	7.20	18.85	3.65	18.55	4.52	.249	7.74

Fraction of whole soil (per cent)	Size	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Organic matter	Combined water
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
0.6	<0.1μ	1.12	1.46	1.26	0.31	0.73	0.07	0.55	33.45	12.56
	Duplicate	1.15	1.44	1.27	.31	.71	.07	.56	33.30	12.70
	Mean	1.14	1.45	1.27	.31	.72	.07	.56	33.37	12.63
0.8	0.1μ–0.3μ	1.26	1.33	1.93	.37	.86	.11	.49	29.21	9.59
	Duplicate	1.29	1.27	1.88	.36	.84	.11	.47	29.28	9.43
	Mean	1.28	1.30	1.91	.37	.85	.11	.48	29.25	9.51
1.7	0.3μ–1μ	1.23	.78	2.51	.49	.93	.08	.27	25.55	9.13
	Duplicate	1.23	.74	2.47	.44	.93	.08	.27	25.38	9.42
	Mean	1.23	.76	2.49	.47	.93	.08	.27	25.46	9.28
1.9	1μ–5μ	1.38	.89	2.96	.42	.94	.07	.27	23.00	9.45
	Duplicate	1.38	.85	2.75	.42	.92	.07	.28	23.36	9.04
	Mean	1.38	.87	2.86	.42	.93	.07	.28	23.18	9.26
7.1	5μ–50μ	1.31	.63	4.22	1.23	1.10	.07	.04	9.68	5.52
	Duplicate	1.32	.58	4.32	1.14	1.10	.07	.04	9.57	5.56
	Mean	1.32	.60	4.27	1.19	1.10	.07	.04	9.63	5.54

There is in the Becket soil a much more pronounced segregation of iron oxide in the direction of the smaller particle sizes and this segregation is evidenced also in the distribution of the alumina.

The sharp differentiation which occurs in the Amarillo and the Marshall soils between the largest colloid particles and clay does not appear in the Becket soil until the silt size is reached, and even here the contrast is not so great. The relation between the total base content and the silica in the Becket is of considerable interest. The ratio

is smaller than in the more nearly saturated colloids and alters rapidly with increasing particle size. This condition is probably due to the enormous organic content and does not indicate even a close approach to saturation of the colloid acid complex. The pH value for this soil is 4.1 and the base saturation is but 16.8 per cent (*3*). The organic-matter content is greatest in the finest particles, which is in contrast with the Amarillo and Marshall colloids. Since the Becket profile has a much greater organic content in the B horizon than in the bleicherde (*10*), the inference may be drawn that not only is the organic matter of the Becket soil decomposed to an advanced degree, but that it has been carried down through the profile in intimate association, perhaps chemical combination, with the iron of the colloid. That it exists in the B horizon in chemical combination does not follow. (See General Discussion.)

TABLE 11.—*Chemical composition of fractions of colloids, clay, and silt from a lateritic soil, Davidson clay loam, B_1 horizon, 9-36 inches depth*

Fraction of whole soil	Size	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio: $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$
Per cent		*Per cent*	*Per cent*	*Per cent*					
14.0	<0.1μ	36.05	15.44	32.02	1.46				
	Duplicate	36.05	15.60	31.87	1.46				
	Mean	36.05	15.52	31.95	1.46	6.21	1.91	0.308	19.71
26.9	<0.3μ	36.13	16.05	31.49	1.47				
	Duplicate	36.20	15.90	31.43	1.47				
	Mean	36.17	15.98	31.46	1.47	6.00	1.94	.324	22.27
7.5	0.3μ–1μ	36.65	14.72	30.73	1.55				
	Duplicate	36.75	14.69	30.86	1.55				
	Mean	36.70	14.71	30.80	1.55	6.61	2.01	.304	24.18
3.4	1μ–2μ	39.75	12.26	30.30	1.77				
	Duplicate	39.80	12.30	30.22	1.77				
	Mean	39.78	12.28	30.26	1.77	8.60	2.22	.259	29.85
6.0	2μ–5μ	49.38	8.51	27.53	2.53				
	Duplicate	49.30	8.53	27.47	2.53				
	Mean	49.34	8.52	27.50	2.53	15.37	3.27	.198	23.85
12.6	5μ–50μ	63.40	6.52	19.77	4.41				
	Duplicate	63.35	6.51	19.73	4.42				
	Mean	63.37	6.52	19.75	4.42	25.80	5.43	.210	42.22

Fraction of whole soil	Size	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Organic matter	Combined water
Per cent		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
14.0	<0.1μ	0.65	0.60	0.34	0.23	0.56	0.13	0.19	2.06	12.04
	Duplicate	.65	.62	.35	.25	.58	.13	.17	2.05	11.94
	Mean	.65	.61	.35	.24	.57	.13	.18	2.06	11.99
26.9	<0.3μ	.51	.59	.34	.....	.81	.07	.13	1.45	12.24
	Duplicate	.50	.62	.32	.....	.83	.08	.14	1.49	12.32
	Mean	.51	.60	.33	.....	.82	.08	.14	1.47	12.28
7.5	0.3μ–1μ	.52	.61	.56	.....	1.46	.07	.19	1.30	12.92
	Duplicate	.49	.69	.56	.....	1.40	.07	.18	1.29	12.93
	Mean	.51	.65	.56	.....	1.43	.07	.19	1.30	12.93
3.4	1μ–2μ	.69	.38	.90	.....	1.76	.08	.28	1.50	11.80
	Duplicate	.65	.31	.86	.....	1.74	.09	.29	1.44	11.86
	Mean	.67	.35	.88	.....	1.75	.09	.29	1.47	11.83
6.0	2μ–5μ	.73	.18	1.05	.15	1.81	.04	.16	1.40	9.86
	Duplicate	.80	.18	1.01	.13	1.81	.04	.16	1.51	9.81
	Mean	.77	.18	1.03	.14	1.81	.04	.16	1.46	9.83
12.6	5μ–50μ	.60	.16	.73	.08	1.51	.08	.02	.78	6.99
	Duplicate	.58	.12	.70	.13	1.51	.08	.02	.76	7.01
	Mean	.59	.14	.72	.11	1.51	.08	.02	.77	7.00

In Table 11 are shown the analytical data for the fractions of the B_1 horizon of Davidson clay loam. This sample is a part of the same profile reported by Middleton (*22*). The soil is a mature red soil from the piedmont area and is highly lateritic, as indicated by the silica-sesquioxide ratio. The iron oxide content of the soil is high. In the A horizon it is 6.1 per cent; in the B_1 horizon, 10.62 per cent; in the B_2 horizon, 14.87 per cent; and in the C horizon, 13.37 per cent (*22*). While this marked alteration of the iron oxide content within the profile is occurring, the change in the alumina content of the B_1 and B_2 horizons alters but 0.18 per cent. These facts indicate clearly a distinct transfer of iron oxide from the surface soil to the lower part of the profile, although to less marked extent than in the Becket and Superior podzols examined by Anderson and Byers (*3*). A much less distinctly marked alteration of alumina content occurs in the soils.

In accord with this behavior of the soils a distinct concentration of iron oxide is found in the finer part of the colloid, as indicated by the silica-iron oxide ratios of 6.61 and 6.00 for the 0.3 to 1-micron and below 0.3-micron fractions. (It is to be noted that in Table 10 the 0.3-micron fraction includes the material below 0.1 micron.) This alteration of the iron-oxide content is less marked than in the Becket colloid. The fact that a corresponding concentration of alumina in the finer fraction does not occur is shown by the iron oxide-alumina ratios 0.324 and 0.304. When these facts are considered in the light of the corresponding data of Table 9 and those given for the B_2 horizon of Cecil clay loam (Table 12) and for the profile of the same soil reported by Denison (*14*), it is difficult to avoid the conclusion that iron oxide is carried from the upper to lower levels in a very fine state of subdivision, or possibly in true solution, with organic acids of the humus type. That alumina is not so transferred, or at least is not deposited, is also clear. The close approach of the silica-alumina ratio to 2.0 in the colloid fractions indicates the presence in the colloid of but little free alumina and that the "laterization" of the colloid is confined largely, if not wholly, to the iron compounds of the soil material.

The extremely high silica-base ratios are of marked interest because they indicate the high degree of leaching which has taken place. It would appear, however, that the silica-alumina ratio should indicate a fair base-exchange capacity. The base-exchange capacity of this profile has been shown by Anderson and Byers (*3*) to be 0.183, 0.126, and 0.158 milliequivalents for the A, B_1, and B_2 horizons, respectively. This is in marked contrast with a true ferruginous laterite, Nipe clay, which has nearly zero base-exchange capacity (*10*).

In this colloid a distinct accumulation of organic matter is found in the finer fractions, but this accumulation is relatively and in quantity not quite so great as in the podzol (Table 9) and is not associated with so large an alteration of the content of combined water. No very definite conclusions are to be based on data so quantitatively uncertain as are the organic and combined water values (*5*), but it seems probable that these differences are to be associated with the mean annual temperatures under which these soils have been developed.

Table 12 contains the data on the chemical composition of the size fractions of the colloid of a B_2 horizon of a Cecil clay loam from North Carolina. It is derived from the same profile but not the same sample reported by Denison (*14*). It is a more highly laterized soil than the Davidson, and the soil material is disintegrated to a much greater depth. The profile analyses of the colloid show close similarity to the extensive investigation of Cecil colloids as reported by Holmes and Edgington (*17*).

TABLE 12.—*Chemical composition of fractions of soil colloids, clay, and silt, from a lateritic soil, Cecil clay loam, B_2 horizon, 36–72 inches depth*

Fraction of whole soil (per cent)	Size	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio: $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$
		Per cent	*Per cent*	*Per cent*					
1.4	<0.1μ	33.83	15.50	32.17	1.37				
	Duplicate	33.72	15.52	32.25	1.35				
	Mean	33.78	15.51	32.21	1.36	5.78	1.77	0.307	21.91
2.5	0.1μ–0.3μ	34.04	13.02	34.26	1.35				
	Duplicate	34.25	13.01	34.04	1.37				
	Mean	34.15	13.02	34.15	1.36	6.96	1.67	.243	28.56
1.0	0.3μ–1μ	35.80	11.00	32.29	1.54				
	Duplicate	35.78	11.00	32.24	1.54				
	Mean	35.79	11.00	32.27	1.54	8.77	1.87	.217	21.23
1.4	1μ–5μ	37.20	10.55	33.71	1.58				
	Duplicate	37.21	10.59	33.61	1.56				
	Mean	37.21	10.57	33.66	1.57	9.35	1.87	.200	17.23
9.5	5μ–50μ	41.50	8.00	33.73	1.81				
	Duplicate	41.40	8.20	33.93	1.79				
	Mean	41.45	8.10	33.83	1.80	13.58	2.07	.153	16.17

Fraction of whole soil (per cent)	Size	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Organic matter	Combined water
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1.4	<0.1μ	0.43	0.41	0.36	0.24	0.94	0.24	0.29	3.33	12.71
	Duplicate	.40	.41	.37	.23	.92	.23	.31	3.52	12.54
	Mean	.42	.41	.36	.24	.93	.23	.30	3.43	12.62
2.5	0.1μ–0.3μ	.33	.31	.27	.13	1.12	.21	.30	3.65	12.73
	Duplicate	.35	.35	.26	.15	1.14	.21	.31	3.58	12.77
	Mean	.34	.33	.27	.14	1.13	.21	.31	3.62	12.75
1.0	0.3μ–1μ	.51	.42	.44	.20	1.46	.24	.50	4.89	11.99
	Duplicate	.51	.41	.42	.20	1.48	.24	.52	4.91	12.05
	Mean	.51	.42	.43	.20	1.47	.24	.51	4.90	12.02
1.4	1μ–5μ	.81	.46	.68	.00	.84	.20	.65	2.59	12.20
	Duplicate	.76	.43	.72	.01	.78	.18	.70	2.71	12.10
	Mean	.79	.45	.70	.01	.81	.19	.68	2.65	12.15
9.5	5μ–50μ	.79	.34	1.17	.29	1.25	.13	.62	1.16	11.80
	Duplicate	.75	.34	1.19	.28	1.25	.13	.62	1.03	11.97
	Mean	.77	.34	1.18	.29	1.25	.13	.62	1.10	11.88

Here the evidence of podzolization as shown by increase of the silica-iron oxide ratio, silica-alumina ratio, and by the change of the ferric oxide-alumina ratio in colloid fractions is also found, as was also shown by Byers and Anderson (*10*) for the A and B horizons of the profiles of Cecil soils in general. In accordance with these properties of the colloid of the Cecil profile distinct alteration of colloidal properties with colloidal size are found. (Table 11.) As with the Davidson colloid, the silica-alumina ratio is fairly close to 2.0 and increases

gradually toward the coarser particles. The schist from which the soil is formed contains but little quartz, and hence there is not the sudden increase of the various silica ratios as the clay and silt sizes are reached. The analyses of both silt and clay fractions indicate unquestionably the presence of increasing quantities of undecomposed, or only partly decomposed, schistose material. In this colloid no marked alteration of the organic content or of the combined water occurs, and in this respect it resembles the behavior of the colloids of the Amarillo and Marshall soils. It is probable that this fact is due in part to the extremely deep and porous character of the profile, which allows the finely divided material to penetrate to greater depths before deposition.

The very high silica-base molecular ratios show the soil to be extremely highly leached, despite the relatively high organic content which might be expected to aid the retention of the bases.

In Table 13 are presented data from the C_3 horizon of a lateritic soil, Durham sandy loam, from near Stone Mountain, Ga. It is the decomposition material from granite, and the decay has proceeded sufficiently far for rather complete disintegration of the rock. The profile is the same as that on which data are reported by Denison (*14*), but the sample is not identical. The soil is derived from a rock low in iron, and the colloid is therefore low in iron oxide, though there is a much larger amount in the colloid than in the whole soil. The value of the silica-alumina ratio indicates a mature soil, as does also the extremely extensive removal of the bases. On the other hand, the rapid increase in the potassium content of the coarser particles indicates the presence of much undecomposed micaceous or feldspathic material. The presence of these is confirmed by petrographic examination. The presence of such relatively large amounts of organic material at so great a depth and its failure to be present in increased quantity in the finer fractions indicates the transfer of considerable material from the upper soil strata and that it probably acts as a cementing material to limit the ease of dispersion. In the analytical data the fraction below 0.3 micron includes the finer fraction below 0.1 micron. The relatively high combined water also indicates the presence of hydrated oxides or colloidal mica. It is with these facts in mind that the authors hazard the opinion that this material consists in part of raw colloid of high silica-sesquioxide ratio, formed in place and in part of completely laterized material carried down from the upper strata. This assumption is in harmony with the data presented by Denison (*14*) on a different sample of the same soil, though the silica-sesquioxide ratio for the corresponding horizon in that sample is much less than in the present one, and the organic and combined water content are correspondingly greater.

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TABLE 13.—*Chemical composition of fractions of soil colloids, clay, and silt, from a lateritic soil, Durham sandy loam, C_3 horizon, 90–102 inches depth*

Fraction of whole soil (per cent)	Size	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio: $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	Molecular ratio: $\frac{SiO_2}{Fe_2O_3}$	Molecular ratio: $\frac{SiO_2}{Al_2O_3}$	Molecular ratio: $\frac{Fe_2O_3}{Al_2O_3}$	Molecular ratio: $\frac{SiO_2}{\text{Total bases}}$
		Per cent	*Per cent*	*Per cent*					
10.7	<0.1μ	41.38	3.57	37.90	1.75				
	Duplicate	41.50	3.67	38.00	1.75				
	Mean	41.44	3.62	37.95	1.75	30.32	1.85	0.060	30.8
20.5	<0.3μ	41.57	3.56	39.15	1.70				
	Duplicate	41.53	3.54	39.38	1.69				
	Mean	41.55	3.55	39.27	1.70	31.06	1.79	.057	27.0
2.9	0.3μ–1μ	40.13	3.15	39.38	1.64				
	Duplicate	40.13	3.20	39.48	1.64				
	Mean	40.13	3.17	39.43	1.64	33.59	1.74	.051	20.0
2.9	1μ–5μ	39.39	3.46	37.39	1.69				
	Duplicate	39.37	3.39	37.44	1.68				
	Mean	39.38	3.43	37.42	1.68	30.66	1.78	.058	14.3
6.5	5μ–50μ	48.73	2.28	33.22	2.38				
	Duplicate	48.80	2.36	33.17	2.38				
	Mean	48.77	2.32	33.20	2.38	52.50	2.45	.045	15.2

Fraction of whole soil (per cent)	Size	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Organic matter	Combined water
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
10.7	<0.1μ	0.54	0.44	0.50	0.29	0.31	0.03	0.13	1.39	13.50
	Duplicate	.55	.45	.52	.24	.29	.03	.12	1.38	13.53
	Mean	.55	.45	.51	.27	.30	.03	.13	1.39	13.52
20.5	<0.3μ	.41	.23	.66	.30	.39	.03	.03	.98	13.48
	Duplicate	.37	.25	.66	.32	.39	.02	.03	.91	13.47
	Mean	.39	.24	.66	.31	.39	.03	.03	.94	13.48
2.9	0.3μ–1μ	.43	.33	.97	.36	.43	.06	.10	1.93	13.58
	Duplicate	.43	.31	.97	.40	.43	.06	.10	1.87	13.68
	Mean	.43	.32	.97	.38	.43	.06	.10	1.90	13.63
2.9	1μ–5μ	.65	.45	1.42	.45	.41	.04	.24	3.30	13.08
	Duplicate	.68	.45	1.39	.48	.41	.05	.22	3.37	12.77
	Mean	.67	.45	1.40	.47	.41	.05	.23	3.34	12.93
6.5	5μ–50μ	.53	.46	2.37	.48	.36	.05	.20	1.53	10.51
	Duplicate	.50	.45	2.45	.46	.36	.05	.21	1.56	10.39
	Mean	.52	.46	2.41	.47	.36	.05	.21	1.55	10.45

The soil fractions represented by the data in Table 14 are derived from the C_4 horizon of a Cecil sandy clay loam from De Kalb County, Ga. It is from the same location as the profile reported by Denison (*14*) but is a different sample. The profile is that of a highly developed laterite in which the weathering of the micaceous schist has penetrated to considerable depth. The soil material, making up the various layers of the C horizon, consists of numerous wavy bands of material of different colors. The material represented in Table 14 consists of several such bands. The analyses of the colloidal fractions indicate a very high degree of weathering, even at a depth of more than 112 inches. The total colloid, as estimated by mechanical analysis, (2 microns and less) is but 1.7 per cent (Table 3), and of this quantity 88 per cent (1.5 per cent of the soil) is represented in the analytical data and approximately two-thirds of it in the fractions below 0.3 micron. Although the colloid of this profile contains a considerable quantity of iron oxide, its concentration is greatest in

the very fine fraction. That this content of iron oxide is greater in the fraction between 0.3 and 1 micron is perhaps due to the difficulty in dispersing the incipient "iron" concretions observable in larger sizes in soils of the general character of the Cecil series. Attention is also called to the fact that although the silica-sesquioxide ratio indicates a highly laterized colloid, the silica-alumina ratio closely approaches that of kaolin. If the considerations presented later are accepted as well grounded, this may be taken to indicate that practically all the iron content of the soil is present as the sesquioxide and that most of the aluminium is present as alumino silicate. The high organic-matter content of this deep-lying material is to be taken as evidence that the source of at least a large part of the colloid is from the overlying strata. The extreme poverty of the colloid of the finer fractions in bases is in accord with this assumption.

TABLE 14.—*Chemical composition of fractions of soil colloids, clay, and silt from a lateritic soil, Cecil sandy clay loam, C_4 horizon, 180–196 inches depth*

Fraction of whole soil (per cent)	Size	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio				
					$\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{\quad}{Fe_2O}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$
		Per cent	*Per cent*	*Per cent*					
0.3	<0.1μ	33.88	14.15	30.34	1.46				
	Duplicate	33.84	14.16	30.33	1.46				
	Mean	33.86	14.16	30.33	1.46	6.35	1.89	0.297	27.11
.8	0.1μ–0.3μ	38.66	9.21	33.55	1.67				
	Duplicate	38.60	9.18	33.42	1.67				
	Mean	38.63	9.20	33.48	1.67	11.14	1.95	.175	26.30
.4	0.3μ–1μ	35.06	13.92	29.75	1.54				
	Duplicate	35.04	13.94	29.73	1.53				
	Mean	35.05	13.93	29.74	1.54	6.69	1.99	.292	13.77
.8	1μ–5μ	34.64	18.44	29.30	1.43				
	Duplicate	34.50	18.25	29.49	1.42				
	Mean	34.57	18.35	29.40	1.43	4.96	1.99	.400	10.14
4.0	5μ–50μ	41.91	11.15	30.02	1.91				
	Duplicate	41.91	11.19	29.97	1.91				
	Mean	41.91	11.17	30.00	1.91	9.97	2.36	.237	9.98

Fraction of whole soil (per cent)	Size	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Organic matter	Combined water
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
0.3	<0.1μ	0.65	0.43	0.56	0.14	0.80	0.54	0.20	6.86	11.68
	Duplicate	.65	.39	.53	.13	.80	.56	.22	6.71	11.75
	Mean	.65	.41	.55	.14	.80	.55	.21	6.79	11.72
.8	0.1μ–0.3μ	.55	.39	.79	.05	.64	.32	.30	3.86	11.94
	Duplicate	.57	.39	.78	.08	.64	.32	.28	3.81	12.04
	Mean	.56	.39	.79	.06	.64	.32	.29	3.84	11.99
.4	0.3μ–1μ	1.05	.51	.42	.21	.99	.56	.39	5.09	11.91
	Duplicate	1.03	.45	.44	.28	1.01	.56	.40	5.15	11.80
	Mean	1.04	.48	.43	.25	1.00	.56	.40	5.12	11.85
.8	1μ–5μ	1.40	.34	1.26	.20	1.22	.62	.44	3.08	11.77
	Duplicate	1.32	.36	1.30	.13	1.24	.62	.42	2.90	11.95
	Mean	1.36	.35	1.28	.17	1.23	.62	.43	2.99	11.86
4.0	5μ–50μ	1.60	.38	1.91	.31	1.05	.42	.18	1.65	10.05
	Duplicate	1.55	.38	1.76	.21	1.07	.40	.17	1.68	10.03
	Mean	1.58	.38	1.83	.26	1.06	.41	.18	1.66	10.04

TABLE 15.—*Chemical composition of fractions of colloids, silt, and clay, from Cecil clay loam, C_3 horizon, 112+ inches depth*

Fraction of whole soil (per cent)	Size	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio: $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$
		Per cent	*Per cent*	*Per cent*					
2.6	<0.1μ	13.95	2.03	53.08	0.436				
	Duplicate	14.10	2.02	53.02	.443				
	Mean	14.02	2.03	53.05	.439	1.83	0.46	0.024	7.24
5.2	<0.3μ	13.01	1.89	56.75	.374				
	Duplicate	13.06	1.81	56.56	.378				
	Mean	13.04	1.85	56.65	.376	1.87	.39	.021	16.93
2.9	0.3μ-1μ	15.47	2.48	51.73	.484				
	Duplicate	15.58	2.45	51.66	.489				
	Mean	15.52	2.47	51.69	.487	1.66	.51	.031	10.38
3.9	1μ-5μ	19.78	4.11	45.73	.692				
	Duplicate	19.82	4.11	45.84	.694				
	Mean	19.80	4.11	45.78	.693	1.28	.73	.055	8.14
6.9	5μ-50μ	34.70	7.26	35.33	1.47				
	Duplicate	34.69	7.22	35.40	1.47				
	Mean	34.70	7.24	35.36	1.47	1.27	1.66	.130	9.51

Fraction of whole soil (per cent)	Size	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Organic matter	Combined water
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2.6	<0.1μ	0.48	0.60	0.22	0.19	0.48	0.31	1.06	4.02	23.80
	Duplicate	.46	.62	.20	.22	.46	.33	1.06		
	Mean	.47	.61	.21	.21	.47	.32	1.06		
5.2	<0.3μ	.34	.35	.26	.17	.35	.16	.76	2.73	24.39
	Duplicate	.35	.37	.26	.15	.35	.16	.78	2.74	24.30
	Mean	.34	.36	.26	.16	.35	.16	.77	2.74	24.35
2.9	0.3μ-1μ	.51	.63	.46	.35	.41	.08	.85	4.56	22.89
	Duplicate	.53	.61	.43	.37	.43	.08	.86	4.56	22.96
	Mean	.52	.62	.44	.38	.43	.08	.86	4.56	22.92
3.9	1μ-5μ	.89	.41	.74	.21	.49	.17	.87	5.80	20.40
	Duplicate	.91	.39	.72	.16	.49	.16	.86	5.77	20.40
	Mean	.90	.40	.73	.19	.49	.16	.87	5.79	20.40
6.9	5μ-50μ	1.25	.47	1.56	.29	.93	.16	.78	2.51	14.35
	Duplicate	1.26	.47	1.56	.27	.91	.17	.79	2.54	14.11
	Mean	1.25	.47	1.56	.28	.92	.17	.78	2.53	14.23

The analytical data presented in Table 15 are derived from the C_3 horizon of the same profile sample as the B_2 horizon which is the source of the data of Table 12. The data given for this horizon by Denison (*14*) are derived from the same locality but from a different sample. It is to be observed that this Cecil soil is presumably derived from gneiss, whereas the soil represented by Table 14 is derived from micaceous schist. The sample under consideration is the composite of but two or three bands of nearly white coarsely granulated material, high in sands and gravel, and containing an unusually large percentage of colloid at such great depth. The silica-sesquioxide, silica-iron oxide, and silica-alumina ratios are all abnormally low. The organic matter and combined water content are abnormally high, as is also the phosphate. The organic matter may be considered as limiting to some extent the ease of dispersion. There is no regularity in the silica-base ratio, but the concentration of the bases as well as of the phosphoric acid is greatest in the finest fraction.

There is of course a strong inclination to assume that colloid accumulation at so great a depth in material having a pH value of less than 5 has been formed in place. It would be necessary in this case to assume further that the feldspathic decay produces aluminum hydroxide as a primary step, or, at least, as a secondary result, which keeps almost abreast of the primary hydrolysis. Such formation of aluminium hydroxide is highly improbable. In view, however, of the high content of organic matter, which presumably must have been carried down, the writers prefer to assume that both the alumina and the organic matter have been deposited at this depth either from colloidal suspension or from solution as a result of the surface alkalinity of the feldspathic material to which attention has been strongly directed by Cushman (*12*) and others. The process may, in this case, be assumed to be a species of podzolization in which the iron oxide may have been deposited at higher levels and the alumina carried to greater depths. Whether such a process has actually occurred is not to be asserted positively, but it leads to the suspicion that the same type of fractionation of colloids, which results in the production of podzolic ortstein layers, may also result in the segregation of alumina at lower levels. This accords with the data on the precipitation of aluminium hydroxide by Blum (*8*).

WATER VAPOR ABSORPTION AND HEAT OF WETTING

In Table 16 are presented the data on the water vapor absorption over 3.3 per cent sulphuric acid, over 30 per cent sulphuric acid, and the heat of wetting of the fractions of the eight colloids examined. The ratio of the amount of water absorbed over 3.3 per cent acid to that over 30 per cent is also given. The determination of the water vapor absorption over 30 per cent sulphuric acid was made because it is known, as was pointed out by Anderson (*2*) and Anderson and Mattson (*4*), that even when colloids absorb approximately equal quantities of water from a nearly saturated atmosphere, the quantities may vary widely at lower humidity.

TABLE 16.—*Physical properties of fractions of colloids from various soils*

Sample No.	Soil type	Size	Water vapor absorbed over—		Absorption ratio	Heat of wetting
			3.3 per cent H_2SO_4	30 per cent H_2SO_4	3.3 per cent / 30 per cent	
			Per cent	*Per cent*		*Calories*
4575	Amarillo silty clay loam	<0.1 μ	36.25	19.95	1.82	19.2
		Duplicate	36.80	20.18	1.82	19.0
		Mean	36.48	20.07	1.82	19.1
		0.1–0.3 μ	27.02	13.84	1.95	12.6
		Duplicate	26.85	14.00	1.92	12.8
		Mean	26.94	13.92	1.94	12.7
		0.3–1 μ	25.80	13.51	1.91	12.6
		Duplicate	25.30	13.25	1.91	12.8
		Mean	25.55	13.38	1.91	12.7
		1–5 μ	12.24	6.98	1.76	6.7
		Duplicate	12.15	6.14	1.98	6.7
		Mean	12.20	6.56	1.87	6.7
		5–50 μ	2.53	1.31	1.93	1.2
		Duplicate	2.55	1.28	1.99	1.1
		Mean	2.54	1.30	1.96	1.2

TABLE 16.—*Physical properties of fractions of colloids from various soils*—Contd.

Sample No.	Soil type	Size	Water vapor absorbed over—		Absorption ratio	Heat of wetting
			3.3 per cent H_2SO_4	30 per cent H_2SO_4	3.3 per cent / 30 per cent	
			Per cent	*Per cent*		*Calories*
		<0.1 μ	30.66	13.49	2.27	14.5
		Duplicate	31.44	12.80	2.45	14.6
		Mean	31.05	13.14	2.36	14.6
		0.1–0.3 μ	25.80	9.18	2.81	10.8
		Duplicate	26.20	9.32	2.81	11.4
		Mean	26.00	9.25	2.81	11.1
		0.3–1 μ	24.58	9.55	2.57	10.0
191	Marshall silt loam	Duplicate	25.20	9.59	2.63	9.9
		Mean	24.89	7.57	2.60	10.0
		1–5 μ	16.25	9.02	2.31	9.5
		Duplicate	15.59	7.15	2.18	9.7
		Mean	15.92	7.08	2.25	9.6
		5–50 μ	2.35	.96	2.45	2.5
		Duplicate	2.31	.99	2.33	2.3
		Mean	2.33	.97	2.39	2.4
		<0.1 μ	30.62	18.68	1.64	18.4
		Duplicate	29.90	18.38	1.62	18.6
		Mean	30.26	18.53	1.63	18.5
		0.1–0.3 μ	23.78	13.36	1.78	17.7
		Duplicate	24.01	13.56	1.77	17.5
		Mean	23.89	13.46	1.78	17.6
		0.3–1 μ	25.02	15.78	1.59	18.0
4447	Becket silt loam	Duplicate	24.66	15.16	1.63	18.0
		Mean	24.84	15.47	1.61	18.0
		1–5 μ	17.61	9.75	1.81	13.4
		Duplicate	17.81	9.96	1.79	13.4
		Mean	17.71	9.86	1.80	13.4
		5–50 μ	7.49	4.17	1.80	6.5
		Duplicate	7.18	4.27	1.68	6.4
		Mean	7.33	4.22	1.74	6.5
		<0.1 μ	34.71	6.07	5.72	6.8
		Duplicate	34.18	5.93	5.78	6.8
		Mean	24.44	6.00	5.75	6.8
		<0.3 μ	18.19	3.39	5.37	3.6
		Duplicate	18.56	3.49	5.32	4.1
		Mean	18.37	3.44	5.35	3.9
		0.3–1 μ	16.15	3.67	4.40	3.6
6263	Durham sandy loam	Duplicate	15.30	3.89	3.94	4.0
		Mean	15.72	3.78	4.17	3.8
		1–5 μ	8.05	2.61	3.08	2.5
		Duplicate	8.27	2.41	3.43	2.7
		Mean	8.16	2.51	3.26	2.6
		5–50 μ	7.02	1.81	3.88	1.5
		Duplicate	7.46	1.83	4.07	1.5
		Mean	7.24	1.82	3.97	1.5
		<0.1 μ	38.91	7.21	5.40	6.4
		Duplicate	38.99	7.27	5.36	6.0
		Mean	38.95	7.24	5.38	6.2
		<0.3 μ	39.32	7.44	5.29	4.1
		Duplicate	38.72	7.39	5.13	4.3
		Mean	39.02	7.42	5.21	4.2
		0.3–1 μ	34.16	5.62	6.08	4.7
4440	Davidson clay loam	Duplicate	33.94	5.42	6.26	4.6
		Mean	34.05	5.52	6.17	4.7
		1–5 μ	14.32	3.44	4.11	3.6
		Duplicate	14.56	3.43	4.25	3.8
		Mean	14.44	3.44	4.18	3.7
		5–50 μ	5.05	1.44	3.51	1.6
		Duplicate	5.20	1.51	3.44	1.5
		Mean	5.12	1.47	3.47	1.6
		<0.1 μ	35.00	5.43	6.46	----------
		Duplicate	36.17	5.56	6.50	----------
		Mean	35.58	5.49	6.48	----------
		0.1–0.3 μ	15.13	3.36	4.70	4.7
		Duplicate	15.59	3.27	4.77	4.6
		Mean	15.36	3.32	4.64	4.7
		0.3–1 μ	17.16	3.56	4.82	----------
6274	Cecil sandy clay loam	Duplicate	17.64	3.08	5.73	----------
		Mean	17.40	3.32	5.28	----------
		1–5 μ	9.78	3.35	2.92	3.5
		Duplicate	9.77	3.25	3.01	3.4
		Mean	9.78	3.30	2.97	3.5
		5–50 μ	5.72	2.12	2.70	2.7
		Duplicate	5.86	2.21	2.65	2.6
		Mean	5.79	2.17	2.68	2.7

TABLE 16.—*Physical properties of fractions of colloids from various soils*—Contd.

Sample No.	Soil type	Size	Water vapor absorbed over—		Absorption ratio	Heat of wetting
			3.3 per cent H_2SO_4	30 per cent H_2SO_4	3.3 per cent 30 per cent	
			Per cent	*Per cent*		*Calories*
6278	Cecil clay loam	<0.1 μ	35.73	5.57	6.42	5.9
		Duplicate	35.90	5.75	6.24	6.4
		Mean	35.81	5.66	6.33	6.2
		0.1–0.3 μ	21.89	3.42	6.11	3.6
		Duplicate	22.90	3.74	6.13	3.8
		Mean	22.39	3.58	6.12	3.7
		0.3–1 μ	13.46	3.35	4.02	3.6
		Duplicate	14.29	2.96	4.83	3.8
		Mean	13.88	3.16	4.43	3.7
		1–5 μ	9.49	2.69	3.53	2.8
		Duplicate	9.58	2.81	3.41	2.9
		Mean	9.53	2.75	3.47	2.9
		5–50 μ	7.80	1.79	4.36	2.3
		Duplicate	7.20	1.89	3.81	2.5
		Mean	7.50	1.84	4.08	2.4
6281	Cecil clay loam	<0.1 μ	14.32	3.54	4.05	
		Duplicate	14.35	3.08	4.65	
		Mean	14.34	3.31	4.35	
		<0.3 μ	15.13	3.13	4.84	4.9
		Duplicate	15.80	3.28	4.82	5.3
		Mean	15.46	3.20	4.83	5.1
		0.3–1 μ	13.01	3.35	3.89	5.8
		Duplicate	14.10	3.77	3.74	5.3
		Mean	13.56	3.56	3.81	5.6
		1–5 μ	10.22	2.91	3.51	4.7
		Duplicate	10.21	2.84	3.60	4.4
		Mean	10.22	2.88	3.56	4.6
		5–50 μ	7.93	2.56	3.09	4.2
		Duplicate	8.16	2.55	3.20	4.0
		Mean	8.05	2.56	3.14	4.1

Of the heat of wetting little need be said except that in numerical values the calories of heat evolved per gram are parallel with and nearly the same as the percentage of water absorbed over 30 per cent sulphuric acid. This parallelism has already been mentioned by Anderson (*1*) and by Anderson and Mattson (*4*). The heat of wetting may, of course, be considered as a measure of the energy involved in the absorption process. In general, the values for all three measurements decrease with increasing particle size. In the B_2 horizon of Becket silt loam, the 0.1 to 0.3 micron fraction shows somewhat smaller absorptive values than the fraction of larger size. It is probable that this divergence is associated with the presence in these fractions of exceptionally large amounts of organic matter which, though an excellent absorbent of water, does not necessarily have properties paralleling those of the inorganic material. A lack of uniformity is also shown, though to less degree, by the Marshall surface soil sample, in which the organic matter is also high.

The moisture absorption over 3.3 per cent sulphuric acid varies with the particle size and this fact emphasizes strongly that the method of Robinson (*26*) and of Gile et al. (*15*) for estimation of the quantity of colloid in the soil, is at best a rough approximation, since the absorption varies in the three colloidal fractions (0 to 1 micron sizes) from 13.66 per cent for the coarsest fraction of the Cecil clay loam, C_3 horizon, to 38.91 per cent for the finest fraction of the Davidson clay loam, a difference of 285 per cent of the smaller value. The widest difference in an individual soil is in the B horizon of the Cecil clay loam, where the variation is from 13.88 per cent to 35.73

per cent, about 260 per cent of the smaller value. Of course, the variation from the approximate mean value of the weighted fractions is not so divergent, but it is clear that with a fine colloid the water vapor absorption has not the same significance as in the coarser colloid.

It may be remarked, however, that the method of estimation of colloid was developed, using colloid of about 0.3-micron maximum particle size. If consideration is limited to the smaller fractions, the variation is not so great as when the 0.3 to 1 micron size is included.

That other influences than the particle size, i. e., the surface exposed, plays a part in the vapor absorption is clear from the wide variation in the colloids of the different types. Although the size limits are not necessarily an indication of exact equality of surface, they are near enough to equality to preclude the possibility of surface differences being able to account for the wide differences between similar size fractions of Davidson clay loam and the C_3 horizon of Cecil clay loam (No. 6281), nor for the wide difference between the 0.1 and 0.3 micron fractions of Durham sandy loam and the lack of such difference between the corresponding sizes of the C_3 horizon (No. 6281) of Cecil clay loam. It is possible that the various compositions of the colloids may have an indirect result in altering the size and porosity of the fractions as they are dried down in preparation for the determinations, and these differences are responsible for the variations observed.

That composition probably has a most marked effect is also indicated by the ratio of the moisture absorbed over 3.3 per cent sulphuric acid and over 30 per cent sulphuric acid. The vapor tensions over these solutions at 35° C. are, respectively, 41.36 and 31.31 mm, and the ratio of the water vapor absorbed over 3.3 per cent and 30 per cent acid varies from 6.33 in the 0.1-micron fraction of the B horizon of Cecil clay loam (No. 6278) to 1.64 in the corresponding particle size of Becket silt loam. In each colloid the ratio of moisture absorbed over 3.3 per cent acid to that over 30 per cent is fairly constant in each profile, though the actual quantities of water absorbed vary widely, the widest variation for the same soil being in Cecil sandy clay loam, from 6.48 to 2.68. There is a marked divergence between the group of soils represented by the Amarillo, Marshall, and Becket soils on the one hand and the group represented by the Durham, Davidson, and Cecil soils on the other. In the first group, the mean value for the three colloids of the low silica-base ratio is 2.06, for the high silica-base ratio group of four samples, the Durham, Davidson, Cecil sandy clay loam and Cecil clay loam (No. 6278), is 4.67, and for the C_3 horizon of the Cecil clay loam the mean value of the ratio for the three colloid sizes is 3.86. The meaning of this divergence is not wholly clear. It is true that the colloids in which the difference in water absorption is most seriously affected by a change in humidity are those in which bases are lacking in comparison with the silica. Where the total base is low, i. e., where the silica-base ratio is very high, the water absorption ratio is also high. In the Cecil clay loam, C_3 horizon, the silica-base ratio is intermediate. (Tables 7 to 16.) This relationship is also shown when the silica-base ratio alters markedly with coarsening of the fractions, e. g., compare the value 30.8 for the silica-base ratio with 5.72, the 3.3 : 30 per cent aqueous vapor ratio for the 0.1-micron fraction of the Durham soil with 20 and 4.17 for the 0.3 to 1 micron fraction of the same colloid.

Anderson (*2*) has shown considerable variation in the water vapor absorption over 30 per cent sulphuric acid by colloids where they are saturated with different bases. Although the variations are considerable, it does not appear that they will account for the ratios given in Table 16. Since the corresponding variations, if any, over 3.3 per cent sulphuric acid were not determined, it is not possible, from his data, to determine to what extent the various bases would modify the observed ratios.

There is a possibility that the greater absorption of water by the Amarillo, Marshall, and Becket colloid fractions at lowered humidity might be ascribed to the hydration of the metal cations in the colloidal micelles, but such an assumption is not very reasonable and the evidence is not adequate to support it.

There seems no possible correlation between the 3.3 : 30 per cent moisture ratio and the iron oxide or alumina content of the colloids. The iron oxide content is relatively high in the Amarillo, Marshall, and Davidson soils, in Cecil sandy clay loam, and in the B horizon of Cecil clay loam. It is low in the Durham soil and in the C_3 horizon of Cecil clay loam. The silica-alumina ratio is high in the Amarillo and Marshall samples, moderately high in the Durham, and low in the Davidson and Cecil.

It would be very interesting were it possible to correlate this phenomenon with the assumption of the existence in the colloids of alumino-silicic acids which are hydrated readily and retain their water of hydration when the humidity is low if the acid complexes are true clays of the montmorillonite type, and which are more easily dehydrated if of the halloysitic and lateritic types (*16*). The correlation is shown by the Amarillo, Marshall, and Becket samples which are colloids of the former type, and the Durham, Davidson, and Cecil of the latter types.

Additional evidence that the colloids of high silica-sesquioxide ratio retain water at low humidity is found in the work of Anderson previously cited (*2*). The colloids examined, their silica-sesquioxide ratio, and the water vapor absorption are shown in Table 17, collected from his data.

TABLE 17.—*Water vapor absorption variation of colloids with variation of silica-sesquioxide ratio*

Source of colloid	Silica-sesquioxide ratio	Water absorption per gram over 30 per cent H_2SO_4
Fallon loam (surface soil)	3.88	0.171
Sharkey clay (surface soil)	3.12	.150
Marshall silt loam (surface soil)	2.73	.134
Sassafras silt loam (surface soil)	1.86	.101
Norfolk fine sandy loam (subsoil)	1.60	.081
Cecil loam (subsoil)	1.22	.042
Nipe clay (surface soil)	.35	.054

Also Middleton (*21*) has determined the water vapor absorption of four colloids over varying concentrations of sulphuric acid. From his tables the following data have been abstracted. (Table 18.)

TABLE 18.—*Water vapor absorbed per gram of colloids over varying strengths of sulphuric acid expressed by weight percentages in 120 hours at 35° C.*

Soil type	2 per cent	3.3 per cent [1]	5 per cent	7.5 per cent	10 per cent	16 per cent	30 per cent	42 per cent
	Gram	*Gram*	*Gram*	*Gram*	*Gram*	*Gram*	*Gram*	*Gram*
Cecil clay loam	0.2933	0.2780	0.2294	0.1798	0.1361	0.0959	0.0446	0.0291
Norfolk fine sandy loam	.3449	.3358	.3163	.2981	.2541	.1806	.0766	.0462
Clarksville silt loam	.2958	.2845	.2697	.2524	.2363	.1994	.1098	.0678
Sharkey clay	.4125	.3967	.3552	.3243	.2997	.2646	.1805	.1293

[1] Time exposed, 168 hours.

In all cases the quantity of water absorbed is by no means the same for the four colloids at any humidity, and although it decreases with decrease in humidity the rate of decrease is markedly different in the different colloids. The outstanding differences are shown by the colloid from the Cecil clay loam and that from the Sharkey clay. In the former, alteration between 2 per cent and 42 per cent sulphuric acid is tenfold, whereas in the latter the alteration is but threefold.

In order to bring these differences into sharp relief parts of the data are segregated and the water vapor absorption ratios calculated from them are presented in Table 19. Added to these data are the silica-sesquioxide ratios of the corresponding colloids, as given by Robinson and Holmes (*28*). The colloid samples analyzed were not identical with those used for absorption data but were extracted from the same soil sample.

TABLE 19.—*Water absorbed per gram of colloid over 3.3, 30, and 42 per cent sulphuric acid, and the absorption ratios*

Soil type	Silica-sesquioxide ratio	3.3 per cent H_2SO_4 (165 hours)	30 per cent H_2SO_4 (120 hours)	42 per cent H_2SO_4 (120 hours)	Ratio of 3.3:30 acid	Ratio of 3.3:42 acid
		Gram	*Gram*	*Gram*		
Cecil clay loam	1.34	0.2780	0.0446	0.291	6.23	9.55
Norfolk sandy loam	1.67	.3358	.0766	.462	4.38	7.27
Clarksville silt loam	2.18	.2845	.1098	.0678	2.59	4.18
Sharkey clay	3.23	.3967	.1805	.1293	2.20	3.06

It would appear, therefore, that colloids of high silica-sesquioxide ratio are distinctly more avid for moisture than those more completely weathered. That the differences of avidity shown are due to differences in composition seems clear. It must be admitted, however, that the evidence does not adequately support the assumption made above, though it does make it probable. Also, as will be shown, it is in harmony with the structures given in the general discussion. If this relation be justified it may be assumed further that the colloid characteristic which determines the retention of moisture at low humidity is the same cause which determines the base-holding capacity.

THE DIFFICULTLY EXTRACTABLE COLLOID

As mentioned on page 8, the silts and clays obtained after exhaustive dispersion in water or water made slightly alkaline with ammonia still contain quantities of material of the same general character as that extracted. This is demonstrable by microscopic examination as well as by the differences between the quantities of colloid obtained and the total colloid content obtained by either mechanical analysis or water vapor absorption. That such colloid may differ in character from that extracted by water and ammonia has been recognized. (Pp. 1 and 9.) It seemed desirable to extract

some of this material from the residues so exhaustively extracted as in the samples studied. This was accomplished in the manner and to the extent shown on page 9 for three of the silt and clay fractions; those from a chernozem soil (the Amarillo), a podzol (the Becket), and a lateritic soil (the Davidson). These fractions were then redispersed and separated into two parts; that less than 0.1 micron and that between 0.1 and 1 micron. The analytical data on these samples are shown in Table 20.

TABLE 20.—*Analysis of separates from silt and clay extracted with N/50 NaOH*

Sample No.	Soil type	Fraction of whole soil	Size	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio $\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{MgO, CaO, K_2O}$
		Per cent		*Per cent*	*Per cent*	*Per cent*					
		0.30	<0.1μ	39.27	8.90	21.74					
			Duplicate	39.48	8.92	21.52					
			Mean	39.37	8.91	21.63	2.45	11.75	3.10	0.264	6.75
4575	Amarillo silty clay loam.	.75	0.1μ–1μ	46.94	7.08	19.31					
			Duplicate	47.00	7.02	19.30					
			Mean	46.97	7.05	19.30	3.41	19.35	4.14	.214	7.22
		.55	<0.1μ	15.20	16.14	15.76					
			Duplicate	15.24	16.25	15.85					
			Mean	15.22	16.19	15.80	.99	2.50	1.64	.656	4.53
4447	Becket silt loam	.60	0.1μ–1μ	27.65	16.34	18.11					
			Duplicate	27.73	16.23	18.15					
			Mean	27.69	16.28	18.13	1.65	4.52	2.60	.575	5.12
		.18	<0.1μ	29.24	19.42	24.31					
			Duplicate	29.32	19.40	24.53					
			Mean	29.28	19.41	24.42	1.35	4.011	2.041	.509	13.12
4440	Davidson clay loam	.61	0.1μ–1μ	35.51	12.68	28.90					
			Duplicate	35.48	12.64	28.63					
			Mean	35.50	12.66	28.76	1.64	7.46	2.10	.282	24.73

Sample No.	Soil type	Fraction of whole soil	Size	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Organic matter	Combined water
		Per cent		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
		0.30	<0.1μ	2.19	1.32	1.73	0.43	0.55	0.23	0.33	[1] 23.04	
			Duplicate	2.27	1.32			.57	.21	.31	[1] 23.08	
			Mean	2.23	1.32	1.73	.43	.56	.22	.32	[1] 23.06	
4575	Amarillo silty clay loam.	.75	0.1μ–1μ	1.73	1.10	3.08	.48	1.30	.26	.21	11.05	7.55
			Duplicate	1.76	1.06	3.08	.48	1.30	.27	.22	11.06	7.76
			Mean	1.74	1.08	3.08	.48	1.30	.27	.22	11.06	7.66
		.55	<0.1μ	.74	1.18	1.32	3.17	1.09	.19	.49	36.55	8.28
			Duplicate	.96	1.16	1.30	3.20	1.03	.17	.48	36.90	8.02
			Mean	.85	1.17	1.31	3.18	1.06	.18	.48	36.72	8.15
4447	Becket silt loam	.60	0.1μ–1μ	1.53	1.56	2.06	1.33	1.15	.21	.31	20.96	8.81
			Duplicate	1.68	1.63	2.10	1.36	1.13	.21	.33	20.80	8.71
			Mean	1.60	1.59	2.08	1.34	1.14	.21	.32	20.88	8.76
		.18	<0.1μ	.85	.72	.30	1.11	.99	.17	.32	[1] 22.24	
			Duplicate	.85	.72			.99	.17	.32	[1] 21.84	
			Mean	.85	.72	.30	1.11	.99	.17	.32	[1] 22.04	
4440	Davidson clayloam	.61	0.1μ–1μ	.52	.24	.67	.70	1.65	.27	.17	[1] 18.69	
			Duplicate	.40	.37	.69	.75	1.61	.25	.22	[1] 18.69	
			Mean	.46	.30	.68	.75	1.63	.26	.20	[1] 18.69	

[1] Ignition loss, organic matter, and combined water not determined separately.

These more difficultly extractable colloids differ materially from the colloids obtained in the usual manner, as may be observed by comparison of the data in Table 20 with the corresponding data for the same soils as found in Tables 7, 10, and 11. In order to facilitate their comparison the three major constituents are recalculated for the <0.1-micron fraction on the basis of 100 per cent and brought together in Table 21.

TABLE 21.—*The major constituents of the <0.1-micron fractions of the normal and difficultly extractable colloids*

Soil type	Colloid	Percentage of whole soil	Silica	Iron oxide	Alumina
		Per cent	*Per cent*	*Per cent*	*Per cent*
Amarillo silty clay loam	Normal	19.1	61.80	10.39	27.81
	Difficultly extracted	.3	56.16	12.72	31.10
Becket silt loam	Normal	.6	32.65	28.16	39.22
	Difficultly extracted	.55	32.27	34.27	33.46
Davidson clay loam	Normal	14.9	43.16	18.49	38.35
	Difficultly extracted	.18	40.07	26.61	33.32

That some alteration in the relative quantities of these major colloid constituents may have been produced as a result of solution of silica and alumina by the sodium hydroxide used as a dispersing agent is possible, and that it does occur is shown in the examination of the dispersing solution reported in the data given on the Becket sample in Table 24, but it is not believed to be sufficiently great to produce the alteration of composition shown in Table 21.

The extent and character of the differences in composition may be brought into still greater relief by expressing them as given in Table 22.

TABLE 22.—*Differential percentages of the major constituents in normal and difficultly extractable colloids*

[Data from Table 21]

Soil type	Silica, percentage change	Iron oxide, percentage change	Alumina, percentage change
Amarillo silty clay loam	−5.62	+2.33	+3.29
Becket silt loam	−.38	+6.11	−5.76
Davidson clay loam	−3.09	+8.12	−5.03

It will be observed that in all these samples the iron-oxide content of the difficultly extractable colloid is greater than that of the normally extracted material. In all three samples there is a smaller silica content. In the Amarillo sample the alumina is greater, and in the Becket and Davidson samples it is smaller. The change in relative iron oxide-alumina content is also indicated by the greatly increased numerical value of these ratios, though the alteration is less marked, as should be expected, in the Amarillo colloid. Two explanations of these differences may be considered. It is possible that the sodium-hydroxide dispersing agent brings into suspension in the finest colloid fraction larger amounts of material present in the soil as concretionary material higher in iron oxide content than is the body of the colloid. If this be the case, it must also be granted that in the Amarillo sample this concretionary material is likewise richer in alumina.

It is also possible that the difficultly dispersable material is, for the most part, the film of colloid adhering firmly to the quartz or other undecomposed mineral particles. If this be the case, the differential percentage change should be greatest in the soil which has been subjected to the more intense weathering conditions. In the samples under consideration, the Amarillo has suffered the least and the Davidson the greatest alteration. The intensity of weathering of these soils is undoubtedly in this order. It must be confessed, however, that the present data are inadequate to decide which explanation is better, or whether both are invalid. The colloids coarser than 0.1 micron show the same character of divergence from the more easily extracted material but not to so marked degree. In all three colloids slightly higher silica-sesquioxide and silica-alumina ratios indicate the existence of unhydrolyzed mineral particles, or of quartz in the coarser colloids, and if it be assumed that the iron-oxide content is free from combination with silica, the silica-alumina ratios indicate montmorillonitic clay in the Amarillo colloid, some admixture of montmorillonitic clay in the Becket, and halloysitic clay in the Davidson. (See General Discussion.)

The relative quantity of the difficultly extractable colloid is much greater in the colloid of Becket silt loam than in that of the other two soils. That this difference is due to the influence of the organic matter is without question. It is probable that the influence is exerted through the cementing effect of the "humic acid" rather than through chemical combination with the iron oxide component. M. S. Anderson, of this bureau, has accumulated data, as yet unpublished, tending to show that ferrous iron is capable of direct combination with humic acid, but that ferric oxide is not. The cementing organic matter may, however, be associated with bases, particularly with calcium and magnesium. It is therefore suggested that under humid conditions, organic ferrous compounds are leached from the bleicherde and deposited in intimate *mixture*, instead of in chemical combination, in the ortstein layer as ferric hydroxide and humic acid. The ferric hydroxide is, of course, partly dehydrated, and the humic acid is, in part, associated with bases. This mixture may be assumed to be more effectively dispersed by sodium hydroxide of the hydrogen-ion concentration employed in the second dispersion because of the increased solubility of the humic acid. That considerable organic matter is dissolved is shown and will be commented on more fully later. That organic matter in the soil may be a large factor in limiting the dispersability of the colloid material and the effect of higher pH values is also shown by the increased organic content up to and including the clay fraction of the Amarillo colloid, as shown in Table 8. The quantity of the difficultly extractable colloid obtained from this sample was insufficient to allow the determination of the organic matter in it, but the ignition loss indicates beyond question the still greater organic content of the finer fractions of this material. The Davidson colloid shows the same effect of the sodium hydroxide used in the extraction process in increasing the organic content of the difficultly dispersable colloid.

It was to have been expected that the use of sodium hydroxide as a dispersing agent would modify the base content of the difficultly dispersable colloid in two ways. There would be more exchangeable bases brought into aqueous solution, particularly when, as in the case of the Amarillo sample, only water was used in the first extraction.

The acid hydrogen (exchangeable hydrogen) should be more completely neutralized by the stronger base, and the sodium salts of the colloid would be more stable than when ammonia of a smaller pH value was employed, as in the Becket and Davidson samples. These expectations are justified by the event. Note the relatively immensely greater increase of sodium content of the Becket and Davidson colloids, as compared with the increase in the Amarillo. The explanation is obvious. The absorption of the sodium is due in but small part to exchange of bases (as indicated by the small quantity of exchangeable bases found in the extract). (Table 24.) The chief cause is the direct neutralization of the soil acids by the sodium hydroxide. Since the sodium salts of the organic material are soluble in water, it is to be presumed that the sodium is held by the inorganic acids.

WATER VAPOR ABSORPTION OF THE DIFFICULTLY EXTRACTABLE COLLOID

In Table 23 are given the percentage quantities of the water vapor absorption over 3.3 per cent sulphuric acid and over 30 per cent sulphuric acid, and the ratio of these values. In the difficultly extractable colloid of the Amarillo sample the percentage values are materially lower than for the corresponding size fractions given in Table 16; indeed, 50 per cent lower in the coarser material, which differs very strikingly from the finer fraction. At the same time, the absorption ratio is higher. This decrease in water absorption is at the same time accompanied with an increase in the percentage of organic matter. (Tables 10 and 20.)

TABLE 23.—*Physical properties of difficultly extractable colloid*

Sample No.	Soil type	Size	Water vapor absorbed over—		Absorption ratio
			3.3 per cent H_2SO_4	30 per cent H_2SO_4	3.3 per cent / 30 per cent
			Per cent	*Per cent*	
4575	Amarillo silty clay loam	<0.1μ	29.85	11.45	2.61
		Duplicate	29.77	11.62	2.56
		Mean	29.81	11.53	2.59
		0.1μ–1μ	12.53	5.45	2.30
		Duplicate	12.65	5.36	2.36
		Mean	12.59	5.41	2.33
4447	Becket silt loam	<0.1μ	32.61	14.50	2.25
		Duplicate	31.82	14.20	2.24
		Mean	32.22	14.35	2.25
		0.1μ–1μ	25.73	11.13	2.31
		Duplicate	25.64	11.15	2.30
		Mean	25.69	11.14	2.31
4440	Davidson clay loam	<0.1μ	32.20	6.67	4.83
		Duplicate	31.64	6.56	4.82
		Mean	31.92	6.61	4.83
		0.1μ–1μ	23.23	3.45	6.79
		Duplicate	23.14	3.15	7.35
		Mean	23.19	3.30	7.07

In the case of the Becket colloid the difficultly extractable colloid differs much less from the easily extractable colloid in the absorption of vapor, and indeed, the values are somewhat greater in the former for the absorption over 3.3 per cent acid. (Table 16.) At the same

time, the organic content of the two fractions of the difficultly extractable colloid differ from each other by the difference between 36.72 per cent for the finer material and 20.96 per cent for the coarser colloid, and in silica-alumina ratio by the difference between 1.64 and 2.60. The organic content of the finer fraction is 3 per cent greater than in the corresponding size of the readily extractable material (Tables 20 and 10) and is nearly 5 per cent less than in the most nearly comparable coarser fraction. The absorption ratio is essentially the same for both fractions, but materially higher than for the more readily extractable colloid. (Table 16.)

In the Amarillo colloid the percentage absorption values over 3.3 per cent sulphuric acid are strikingly lower than for comparable size fractions of the more readily extractable colloid and differ more sharply from each other. For the 30 per cent acid the water vapor absorbed is also sharply different, and, as compared with the more readily extractable colloid, the finer fractions are nearly alike and the coarser fractions differ markedly. The number of samples is not sufficient to permit the drawing of extended conclusions, but it is important to note that the same relationship of the absorption ratio holds with difficultly dispersable colloid, as was noted in the more readily dispersable, viz, the absorption ratio is more than twice as great for the colloids of the montmorillonitic type (see general discussion). Again, it would appear that a plausible explanation is found in the greater stability of the hydrated form of the more complex aluminous acidoid. As a general observation, based on the limited evidence available, it may be said that although the difficultly dispersed colloids differ in many detailed respects from those more readily dispersed, yet in general character the two forms are very similar. It is also clear from the data that the acidoid complexes in the three colloids are of different types.

THE PASTEUR-CHAMBERLAND FILTRATE

In the extraction of the colloids, especially when the addition of ammonia is required to produce approximate neutrality of the dispersing agent, the filtrate through the Pasteur-Chamberland filters (grade F) sometimes shows evidence of the solution of the material, both in the color of the filtrate and in a more or less marked opalescence. That this material is in part colloidal is also evident through the Tyndall effect. In this series of extractions, the depth of color of the filtrate of the Becket silt loam was especially marked, both with the readily and the difficultly dispersed colloid. These filtrates were therefore collected and evaporated to dryness on a steam bath. The filtrates from the extraction with ammonia, with a maximum of 8.5 pH, amounted to 40 gallons and the dry residue weighed 8.8 g or 0.44 per cent of the whole soil. The analysis is given in the first three lines of Table 24. The residue consists of more than 50 per cent organic matter and about 25 per cent moisture. Since the factor 1.724 is by no means accurate (*5*), the organic matter and combined water are not accurately differentiated, but the total quantity, loss-on-ignition, is accurate. Therefore, only about 2 g of ignited inorganic material were carried through the filters in treating 2 kg of the soil. This inorganic material is shown by the analyses to have a considerably higher silica-sesquioxide ratio and a somewhat higher silica-alumina ratio than the colloid (Table 10), but the differences

are suprisingly small. It may be assumed that some extremely finely divided silica, produced by hydrolysis of ammonium silicate, may have found its way into this residue, but if so, the quantity was extremely small. The necessary conclusion is that the extremely finely divided colloid is essentially the same as that constituting the bulk of the finely divided material. The high base content of the ignited residue is without doubt an indication of the nature of the organic matter removed, i. e., that in part it consists of salts of humic acid. It must be kept in mind that this filtrate was from material dispersed with ammonia.

TABLE 24.—*Analyses of residues from wash water of the Becket soil, No. 4447*

Source of material	Fraction of whole soil (per cent)	SiO_2	Fe_2O_3	Al_2O_3	Molecular ratio $\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{TiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$
		Per cent	*Per cent*	*Per cent*					
Residue from 40 gallons of wash water in which the colloid was dispersed at pH 8.5 with NH_4OH.	0.44	6.58	1.33	3.89					
	Duplicate	6.48	1.37	3.88					
	Mean	6.53	1.35	3.89	2.33	13.1	2.86	0.219	1.37
Part of the residue from the wash water from dispersion to pH 10.5–11 with NaOH which precipitates with HCl at pH 5.5, and washed Cl free.	0.13	7.05	2.40	31.12	3.66	7.8	3.84	.005	1.75
Part of filtrate from the above which did not precipitate with N/20 HCl, but after ignition to dull redness all the salts soluble in hot water were removed.	0.28	2.74	.07	12.02	.38	113.0	.354	.0003	.574
Soluble salts from the above of which more than 90 per cent had been added in the successive treatments. 10.5 grams obtained.	0.52	0	0	0					

Source of material	Fraction of whole soil (per cent)	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Organic matter	Combined water
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Residue from 40 gallons of wash water in which the colloid was dispersed at pH 8.5 with NH_4OH.	0.44	0.48	2.55	2.09	4.45	0.15	Trace	0.43	53.10	23.80
	Duplicate	.44	2.53	2.03	4.39	.12	do	.39	51.70	25.17
	Mean	.46	2.54	2.06	4.42	.14	do	.41	52.40	24.49
Part of the residue from the wash water from dispersion to pH 10.5–11 with NaOH which precipitates with HCl at pH 5.5, and washed Cl free.	0.13	2.17	.56	.27	.66	.16			41.64	14.16
Part of filtrate from the above which did not precipitate with N/20 HCl, but after ignition to dull redness all the salts soluble in hot water were removed.	0.28	1.78	1.57	.67	28.89	.04			20.88	31.03
Soluble salts from the above of which more than 90 per cent had been added in the successive treatments. 10.5 grams obtained.	0.52	0	2.43	1.38	48.95	0			0	1.45

The aqueous filtrate from the extraction of the silt and clay residues at a pH value of 10.5 to 11 with sodium hydroxide was particularly highly colored, and its evaporated residue was expected to consist

almost wholly of sodium humate. The residue amounted to 18.6 g of material dried at 105° C. This was redispersed with a small quantity of water and brought to a pH of 5.5 by addition of N/20 HCl. This suspension was allowed to stand for 48 hours and was filtered and washed until free from chlorine. The dried insoluble material was then analyzed. The analysis is given in the fourth line of Table 24. The material lost 56 per cent of its weight on ignition, and the organic material is approximately 42 per cent of the whole. This colloid has a low silica content but has a high silica-sesquioxide and silica-alumina ratio. The suspicion is raised that the greater part of both the silica and alumina is derived from reaction of the sodium hydroxide, used in the extraction, with silicic acid and aluminium hydroxide existing in the silt and clay or produced by hydrolysis in the process of extraction. This suspicion obtains added color from the data discussed in the next paragraph. In any case the quantity of such material, if it exists, must be extremely small, since a part of this material must certainly be normal but extremely finely divided colloid.

The filtrate from the material just described was evaporated to dryness, and, after the carbon content of the residue was determined, it was ignited at low heat. The ignited residue was washed until free from chlorides, and analyzed. The analysis is shown in the fifth line of Table 24. It will be observed that the ignition loss is about 52 per cent, and the analysis indicates that the nonvolatile residue probably is essentially a mixture of sodium silicate, sodium aluminate, and the sodium and other salts of humic acid. The washings from this material were evaporated and analyzed. The analysis shows the residue to be, as was expected, the chlorides of sodium, calcium, and potassium.

The examination of the materials which pass through the Pasteur-Chamberland filters in the case of the Becket silt loam shows that, except for removal of organic matter, the loss of material is extremely slight. That this is in part normal colloid, with addition of small amounts of other material, is indicated. The aqueous extracts from the other colloids were not examined, since it was not believed that the results obtained would pay for the labor expended.

GENERAL DISCUSSION

The data obtained during this study, taken in conjunction with other data, obtained from a study of the same or closely related soils and published elsewhere (*3*, *13*, *23*), warrant a certain amount of general discussion concerning the nature of soil colloids. It has already been brought out by Byers and Anderson (*10*) that the soil colloids of the great soil groups, as established by the soil survey, represent various stages of a progressive degradation of soil material. This degradation is the result of hydrolytic action on the soil minerals and on their primary and secondary products. The degree of hydrolysis, as has been repeatedly pointed out, is governed by a number of agencies. Chief among these are rainfall, temperature, and the character of soil vegetation. Only to a relatively minor degree is the character of the product determined by the character of the primary material. The conclusion that the soil material is of minor importance in determining the character of the soil colloid may be more or less illusory. As estimated by Clarke (*11*), the igneous rocks are approxi-

mately 60 per cent feldspars, the remaining igneous material being quartz, 12 per cent; hornblende and pyroxene, 16.8 per cent; mica, 3.6 per cent; and but 7.9 per cent accessory minerals. It may be then, since hornblende and mica are so frequently associated with feldspars and quartz in granite and similar rocks, that directly or indirectly the soils all have, as far as their primary mineral source is concerned, an essentially common origin. It would follow, therefore, that their immediately antecedent mineral source would be of less moment than the other soil-forming influences in determining their character.

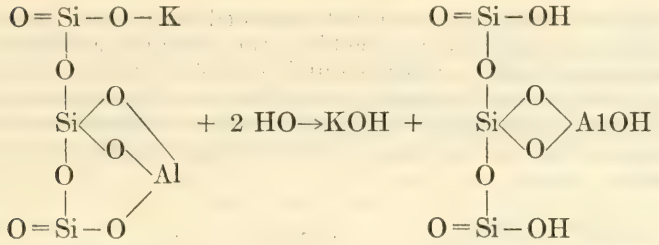
It is assumed that the hydrolysis follows the same course, whether the minerals are ferruginous or aluminous silicates, when they are of the same type, but that in general the hydrolysis proceeds at a slower rate under like conditions for the alumino silicates. It may further be assumed that since, to a very great extent, in the silicate minerals which contain iron it is in the ferrous state, the behavior of this element in the primary hydrolysis will be analogous to that of magnesium and calcium rather than to that of aluminum. If these assumptions are correct it should follow that the soil colloids produced by hydrolysis should differ from each other chiefly with respect to the extent of the hydrolytic action which has occurred and to the extent of transfer of the resultant materials, which in turn will depend on the character of the products. The study of the composition of the colloids of soils representative of the great soil groups (*10*) reveals the fact that there are three general types: Colloids which are essentially alumino silicates of high silica-alumina ratio and correspond in general character to the colloid of montmorillonite; colloids which are essentially of the general type of halloysite with a silica-alumina ratio of approximately 2; and those in which the dominant colloid consists essentially of a mixture of the hydroxide of aluminum, more or less dehydrated, and of iron oxide, more or less hydrated. In the colloids the quantity of ferric oxide may be very variable. The probable existence of these colloid types is strongly supported by recent publications by Hendricks and Fry (*16*), Kelley, Dore, and Brown (*19*), and Baver and Scarseth (*7*).

It must be kept in mind that not only the hydrolytic products of minerals themselves are subject to further hydrolysis, but that they are both acidic and basic at the same time, i. e., amphoteric, as recently emphasized by Mattson (*20*). They are therefore associated with varying amounts and to varying degrees with both basic and acidic ions. The character of a given colloid is also profoundly influenced by the basic, and more especially by the acidic radicals derived from the organic débris accumulated in the soil. With the foregoing facts and assumptions in mind, the character and relationships of the soil colloids may, perhaps, be made clearer by presenting a set of purely hypothetical reactions based on structural formulas of minerals and designed to show the probable results of hydrolysis.[4]

The simplest of the numerous structural formulas which have been proposed for orthoclase is that given below and the general character of hydrolytic action first to be expected is shown in equation 1.

[4] In suggesting these structural formulas it is emphasized that no direct experimental evidence for them is available. They are designed only to present a picture of the sort of changes which, if they occur, would account for the colloid relationships actually found. It is scarcely necessary, perhaps, to add that they have no spatial significance but express chemical relationships only.

1.



Orthoclase — Montmorillonitic acid

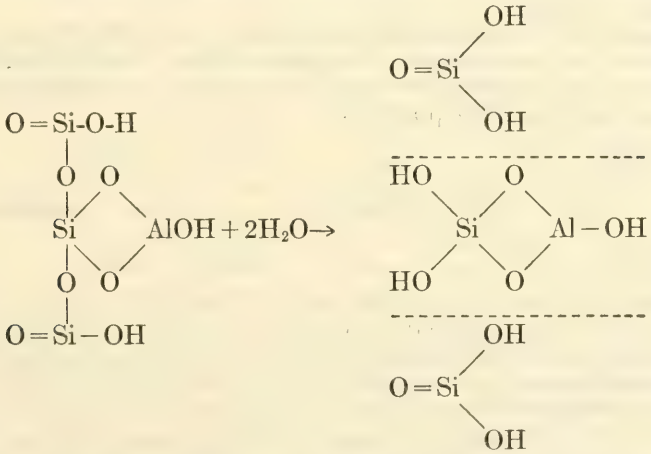
If this reaction takes place as indicated the product called montmorillonitic acid should have a maximum silica-alumina ratio of 6 and should be an amphoteric substance. No such pure compound has been prepared and in view of the known behavior of the polysilicic acids it could not be expected to exist in nature. The nearest approach to it is probably the montmorillonite reported by Ross and Shannon (*29*) in which the silica-sesquioxide ratio is 5.26. This material is not free from iron and yet so far as the original mineral contains ferric iron as a replacement of the aluminium, it may be expected to function in like manner. So far as the iron present in the original material from which the colloid is derived is ferrous iron, it may be expected to behave as indicated in the hypothetical equation for the hydrolysis of hornblende. (Equation 2.)

2. $$Fe\ SiO_3 + 2H_2O \rightarrow Fe(OH)_2 + H_2\ SiO_3$$[5]

In case ferrous hydroxide is produced its further course may vary in detail, but eventually it appears in the soil colloid as ferric oxide or one of its hydrated forms.

If montmorillonitic acid or its acid salts be subjected to further decomposition by hydrolysis the change may be postulated to take place as shown in equation 3.

3.

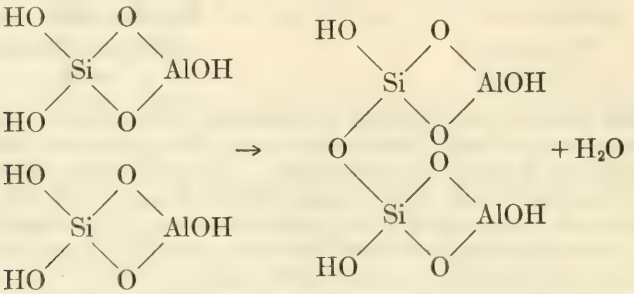


Montmorillonitic acid — Halloysitic acid and metasilicic acid

[5] In hornblende, augite, and many similar minerals, the ferrous iron is present as a salt of metasilicic acid. The following statement is taken from Miers (*24*) and is in point. "Groth, following Zambonini, makes hornblende (like augite) a mixture of $CaMg_3(SiO_3)_4$ with $(MgFe'')(Al\ Fe'')_2(O)_4$ (in pargasite), with the addition in black hornblende of $(Fe'' Al)_2(SiO_3)_3$."

The mixture resulting from the assumed hydrolysis has, if the silicic acid is not removed by leaching, the same silica-alumina ratio as the montmorillonitic material but if completely freed from silicic acid the residue, called halloysitic acid, has the silica-alumina ratio of kaolinitic clay. If it has the assigned formula it differs from the mineral kaolinite by its water content. The distinction may be shown by equation 4.

4.

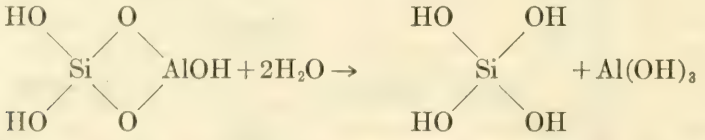


Halloysitic acid Kaolinite

That such a reaction may occur, even in the presence of water, is quite in harmony with the occurrence of many reactions of like type in the case of carbon compounds, and which must be assumed to take place with the silicic acids to account satisfactorily for the existence of salts of the polysilicic acids in minerals. This noncrystalline material is assumed to be the actual "colloidal clay" of highly matured soils which are not laterites. It loses a part of its water readily on heating, as should be expected if it has the structure indicated. It is nevertheless a very stable compound, as shown by the fact that it does not lose all its water component until heated above 550° C. Its stability is also indicated by the enormous quantities of it existing in nature. The corresponding iron compound, nontronite, appears to be much less resistant to change.

It must not be assumed, however, that the halloysitic acid is not subject to further change. The same type of reaction which has occurred as indicated above may be expected to continue with the results as indicated in equation 5.

5.



If this hydrolytic step is followed by leaching of the orthosilicic acid from the material, or its conversion to secondary quartz, we have the last stage of soil formation. The residual material is a true laterite, a dead soil, consisting essentially of the hydroxide of aluminum, which does not dehydrate readily, and of ferric hydroxide, which does dehydrate readily, even in the presence of water, and which in warm or dry areas may become almost completely "hematitized." Complete laterization and removal of silica is not common, and even in tropical areas the hydrolysis of the halloysitic acid must be considered as exceedingly slow. The normal soil for tropical regions ought therefore to contain varying quantities of the halloysitic acidoid complex.

It would then appear, if the writers' speculations are correct, that the progressive hydrolysis of minerals should produce three types of colloids which may be distinguished by the terms montmorillonitic, halloysitic, and lateritic. It must be kept in mind that this hydrolysis *is* progressive and that therefore any soil sample (except, perhaps, the completely weathered laterite) may have present at the same time colloid of all three types and yet one be dominant and be the characteristic form. Besides quartz, the soil may contain undecomposed complex minerals which are subject to hydrolysis, hydrated slowly decomposing mineral matter such as mica, hydrated silica, and such minor mineral particles as may have constituted the rock which formed the parent material. Which of the colloids are present to a dominant degree will be determined by the extent of the weathering that has occurred. The soil-forming processes being very slow, the situation at any one period of time will be that presented by a system in equilibrium even though the reactions are actually in progress. It is therefore a psuedoequilibrium. The situation is comparable with a series of almost infinitely slow moving pictures and the progress of the action may not be followed in any one soil; it can only be followed by comparing pictures of different soils representing different stages of the process.

It also follows from the assumptions made that the amphoteric substances comprising the essential colloid complexes of the normal soils of the Temperate Zone should always contain both basic and acidic radicals derived from the hydrolytic processes on the minerals themselves or from adjacent mineral bodies and carried through the colloids by percolating waters. These "adsorbed" materials may be considered as held by true chemical combination with the colloids. This assumption in no way contradicts the assumption that colloid composition and behavior may also be modified by "surface phenomena."

The passage of water through the soil may occur either essentially in a perpendicular direction or in a direction roughly parallel with the surface. In the former case all materials brought into true solution or colloidal suspension are subject to possible redeposition at greater depths or to complete removal in drainage waters. In the latter case ordinary erosion occurs, and what happens to the suspended material does not concern the soil at lower levels, though it may profoundly affect the soil situation in areas where the eroded material may be deposited. The character of the eluviation by percolating waters will not only be affected by the rate at which it passes but by the character of the material through which it passes before reaching the soil proper. Carbon dioxide absorbed from the air (or possibly other acids from polluted air such as air polluted by smelter or other smoke) or from organic matter, and the organic acids, whether of the humic acid or other types, probably are materials having a very great effect on the soil. In the case of soils developing in areas where the rainfall is insufficient to produce percolation to the depth of the normal water table, no removal of soluble or of colloid material from the profile occurs. Through eluviation and illuviation, alteration of the distribution of colloid within the profile does occur, as is indicated by the zone of accumulation in the chernozem soils. This may be presumed to occur through solution, as calcium bicarbonate, and its redeposition as carbonate at the mean maximum depth of water

penetration. The dry periods following rains do not return the calcium carbonate toward the surface to the same extent as is the case with salts such as the carbonates, sulphates, and chlorides of magnesium, sodium, and potassium. Where percolating water reaches the water table or moves in considerable volume in a horizontal direction, complete removal of soluble or colloidal material from the soil profile may take place.

These elementary considerations may now be applied to the soils examined and reported on in this bulletin. Neither in the profile nor in the colloid fractions in the Amarillo silt loam is there found any material alteration of composition. The chief difference in the profile lies in the quantity of colloid in the different horizons. It is least in the A horizon (23.9 per cent) and greatest in the next lower stratum. It is difficult to escape the conclusion that the part of the colloid not formed in place has moved downward as a whole.[6] There is evidence of alteration of the relative amounts of iron oxide and alumina, as shown by the iron oxide-alumina ratio both for the profile (*3*) and in the fractions. (Table 7.) This may be taken to indicate the presence of some free iron oxide in the colloid. There is also some increase in the silica-sesquioxide ratio of the coarsest colloid. This may be taken as evidence of the presence of free quartz in this fraction. The free quartz is abundantly evident in the clay and silt fractions. The colloid seems to conform closely to the composition of the montmorillonitic type of colloid. This is confirmed by the X-ray examination (*16*). The same type of colloid is present in the Colby silt loam from Kansas reported by Middleton, Slater, and Byers (*23*), and in the Barnes silt loam from South Dakota (*14*) reported by Denison.

The Marshall silt loam, from Nebraska, is not a pedocal soil but is developed under grass cover with sufficient rainfall to produce percolation through the profile and prevent calcium carbonate accumulation. Otherwise the soil is essentially of the chernozem type. Its colloid is rich in bases, though not saturated. The colloid analyses of the profile, so far as determined, show essential constancy of composition. To a minor degree the iron oxide-alumina ratios of the A and B horizons show a slight concentration of iron oxide in the B horizon, yet in view of the increased concentration of colloid in the B horizon the colloid transported downward must have been transported as a whole. The same condition is shown by the fractions of the colloid from the surface layer. (Table 8.) This composition is essentially the same, with slightly greater indication of "podzolization" as indicated by the changes of the iron oxide-alumina ratios. The X-ray photographs (*16*) indicate a colloid of the montmorillonitic type. The silica-alumina ratios indicate the same type. Similar colloids exist in the profile of the Marshall silt loam from Iowa and in the profiles of Shelby silt loam, Houston clay, and Palouse silt loam reported by Middleton, Slater, and Byers (*23*). The evidence so far accumulated therefore shows the prairie soils to contain colloids which have not yet been weathered to the degree corresponding to the products indicated in equation 3 but are intermediate between that condition and the one shown in equation 1.

[6] It is to be recognized that with movements of soil water, particularly in areas of limited rainfall, translocation of soil material may be either downward or upward through the soil profile (*10*), with consequent alteration of colloid content. The point emphasized here is that whatever translocation has occurred has not altered the character of the colloid to a marked degree.

Turning to the soils of the podzol type there is found a strikingly different situation both in the profile and in the colloid fractions. In the Becket silt loam profile the inorganic colloid increases from 0.9 per cent in the surface layer to 5.8 per cent in the B_1 and 5.5 per cent in the B_2 horizons, and the analytical data show marked divergences. (*3*) The soil is developed under heavy rainfall at low annual mean temperature and in the presence of the débris of coniferous forests. The organic matter is carried in large relative quantity to considerable depths. The pH values are extremely low (*3*). The iron oxide-alumina ratios (*3*) indicate very great alteration in passing from the upper to the lower horizons. The silica-sesquioxide ratios for the B_1 and B_2 horizons indicate an apparently lateritic stage of degradation. Even the silica-alumina ratios of the B_1 and B_2 horizons do not reach those required for the montmorillonitic colloid. The X-ray examination, nevertheless, indicates the colloid to be of this type (*16*). The fractions of the colloid (Table 9) also show marked divergences in composition, and the finest fraction shows the highest iron-oxide content. The evidence of the nonhomogeneity of the colloid is very convincing and, in contrast with the chernozem and prairie colloids, indicates that the colloid is fractionated in being transported from higher to lower levels. The base content indicates the probable presence in the colloid of some unhydrolyzed mineral. The same general relations are also shown by the tabulated data for the podzol soil colloids of the Superior fine sandy loam from Wisconsin and the Emmet fine sandy loam from Michigan, and with the podzolic soils of the Miami and the Leonardtown series. It may then be assumed that in the podzol soils the first stage of hydrolysis of soil minerals is represented by the alumino silicate and a part of the iron content (equation 1), and that with this stage of hydrolysis a large part of the iron-oxide content is derived from either the hydrolysis of ferrous minerals (equation 2) or arises as a result of the final hydrolysis of ferruginous clay. (Equation 5.)

When the group of red and yellow soils represented by the five samples examined is considered, a very interesting difference is found between the B horizons, as represented by the Davidson clay loam and Cecil clay loam, and the lower strata of the Durham sandy loam, Cecil clay loam, and Cecil sandy clay loam. In these soils, developed under deciduous forest cover and high temperature and moisture conditions, no such wide contrast is found between the A and B horizons (*3, 10, 14*) as in the podzols, yet the differences are quite distinct and in the same direction. The silica-sesquioxide ratios are less than 2, but the silica-alumina ratios approach closely those required for a colloid of the hallyositic type. (Equation 3.) In the colloid fractions there is a distinct segregation of iron oxide in the finer fractions and a close approach to the proper silica-alumina ratio for clay of the kaolinitic type. The débris of the deciduous forests may produce organic colloid of a less acid type, or the high temperature with alternating dry periods may be responsible for a less complete removal of the iron content of the surface soils as compared with the podzols. This incomplete removal of the laterized iron content does not prevent the almost complete removal of the bases from the hypothetical halloysitic acid which is, as indicated by the work of Baver and Scarseth (*7*), a less active acid than that characterizing the colloids of the chernozem, prairie, and podzol soil types.

The lower degree of hydration of these colloids at lower humidity (Table 6) also indicates that the acid is less stable than the acids of the less weathered soils.

The general relations shown by the two Cecil soils are in harmony with the data presented on a series of soil profiles of the Cecil series, as well as with the data on the Chester series presented by Holmes and Edgington (*17*). When the deep-lying strata of these lateritic soils are considered the quantity of colloid is found to be less than in the strata higher in the profile, and they also have a lower iron-oxide content (*10*). Also, in the fractions of these colloids, small, though distinct, segregation of iron oxide occurs in the finer fractions. In the Durham sandy loam sample, there is little evidence in the C_3 horizon (Table 13) of the existence of free aluminum hydroxide either in the silica-alumina ratio or in the quantity of combined water. The same statement holds for the deep sample of Cecil sandy clay loam. (Table 14.) In the deep stratum of the Cecil clay loam sample (Table 15), on the contrary, there is segregation of iron oxide in the finer colloid fractions, even though the total iron content is small. The extraordinarily low silica-alumina ratio and the high water content indicate either a segregation of alumina or an abnormal local situation. If the former, it would appear possible that a true or colloidal solution of an alumino-organic complex, aluminum humate, has been carried to a point where the surfaces of the weathering feldspars furnish a pH value sufficiently high to induce flocculation. Proof of this statement is admittedly lacking.

In conclusion it should be stated frankly that the writers are quite aware that the above discussion is, in part, not new, and that also, in part, the data presented in the bulletin itself are not adequate to furnish sufficient basis for the assumptions made. It is believed that the comprehensive view, as stated, is warranted by the body of soil colloid data and that the views expressed furnish a basis of correlation of available information which lends itself to the organization of future work. It is further recognized that the statements given are not so fully buttressed by facts as they might be if it were not desirable to make the outline extremely brief.

SUMMARY

The results of an analytical study of eight soil samples derived from seven different profiles are presented.

The samples were fractionated and five fractions analyzed. The fractions were the silt (5 to 50 microns), clay (1 to 5 microns), and three colloidal sizes—finer than 0.1 micron, 0.1 to 0.3 micron, and 0.3 to 1 micron. The dispersion of the colloids was effected by water and, in some instances, with ammonium hydroxide at a maximum pH of 8.7.

The silt and clay fractions of three of the samples were further dispersed with sodium-hydroxide solution at a maximum pH of 11.

The samples included a chernozem, a prairie, a podzol, and three lateritic soils, and from these samples the writers deduce the existence of colloids of three distinct types.

The fractions of the colloids of the chernozem and of the prairie soils show marked similarity in composition and properties within the range of colloidal size. This is interpreted as indicating the persence of a definite and predominating type of colloidal acid.

Fractions of the podzol colloid are characterized by marked variation in chemical composition indicating the existence of a natural fractionation process which is in operation in the soils of this group. The inference is drawn that the podzol colloid is a mixture of at least two substances, iron oxide and the acidoid complex characteristic of the chernozem soils.

The fractions of the lateritic colloids studied show definite differences in composition but not so marked as in the podzols. These differences, when considered along with the profile data published elsewhere, are interpreted to indicate the existence of a colloid complex different from that found in the chernozem, prairie, and podzol colloids.

Certain colloids derived from soil parent material at considerable depths show marked peculiarities of composition, and the data lead to the inference that the colloidal material is in part carried down from higher levels and in part formed in place. The presence in these colloids of completely laterized material is also inferred.

The water vapor absorption over 3.3 per cent sulphuric acid and over 30 per cent sulphuric acid, and the heat of wetting of the soil fractions were also determined. Variations in water vapor absorption between the size fractions of individual soils were very marked, as was also the variation between corresponding soil fractions. From these values and the ratio of the vapor absorbed over 3.3 per cent and 30 per cent sulphuric acid, the inference is drawn that water vapor absorption can not be ascribed to surface alone but is also dependent on chemical composition.

The study of the "difficultly extracted" colloid shows it to be of the same general character as that more easily extracted, though there are marked differences. The fractions are also more divergent in composition than is the case with the more readily dispersed material.

The examination of the filtrates obtained in the extraction of the colloid from one of the samples indicates that the dissolved material is largely organic matter, the inorganic material being less than 0.1 per cent of the whole soil and essentially of the same composition as the fine colloid.

The general discussion of the data, together with data assembled previously, presents a theoretical outline of the origin and nature of soil colloids which the writers believe to be in harmony with the facts presented. According to this outline, the soil colloids represent progressive stages of degradation of complex silicates through hydrolysis, in which are to be distinguished the montmorillonitic acid and halloysitic acid stages and the final or lateritic stage. The two hypothetical acids are both amphoteric. The colloids themselves consist of the partly neutralized salts of these acids and contain both acidic and basic radicals, together with organic colloid. The lateritic colloids possess only very limited base-holding capacity. Since the process of soil formation is continuous, no single colloid can be expected to contain one colloid component only, but in each colloid one component may be expected to dominate. The behavior of the soil will be in general harmony with the chemical properties of its dominant colloid, modified by the presence of other components so far as they occur.

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TECHNICAL BULLETIN No. 318 SEPTEMBER, 1932

EFFECT OF SOLID AND GASEOUS CARBON DIOXIDE UPON TRANSIT DISEASES OF CERTAIN FRUITS AND VEGETABLES

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CONTENTS

	Page
Introduction	1
Review of literature	2
Purpose of the investigation	5
Methods and apparatus	6
Experiments at constant temperatures	6
Experiments in pony refrigerators	7
Experiments in standard refrigerator cars	7
Strawberry experiments	8
Strawberries at constant temperatures	9
Strawberries in pony refrigerators	13
Strawberries in refrigerator cars	17
Peach experiments	21
Peaches at constant temperatures	22
Peaches in pony refrigerators	26
Peaches in refrigerator cars	31
Dewberry experiments	36
Dewberries in pony refrigerators	37
Dewberries in refrigerator cars	40
Experiments with other fruits and vegetables	44
Blackberries	44
Raspberries	45
Blueberries	45
Currants	45
Apricots	45
Cherries	46
Plums and prunes	46
Pears	49
Apples	51
Grapes	52
Oranges and mangos	53
Tomatoes, string beans, and peas	53
Corn, carrots, and cauliflower	53
Discussion	54
Summary	56
Literature cited	58

INTRODUCTION

The effect of abnormal atmospheres on the growth of fungi and on the keeping quality of fruit and vegetables has been a matter of discussion for more than a century, and beneficial effects from different types of gas storage have often been reported. The present studies were undertaken not so much with the idea of developing a method of storage as with the hope of finding at least a partial remedy for the spoilage that results from the warm condition of fruit and vegetable products during the first hours after loading for shipment.

[1] The writers wish to acknowledge their indebtedness to Neil E. Stevens for cooperation in the strawberry and dewberry shipments, and to D. F. Fisher and his associates for cooperation in the shipments in which blower precooling was used. They also wish to express their appreciation of the kind cooperation of growers, and of representatives of the various transportation companies concerned.

It seemed possible that a limited use of solid carbon dioxide might be of value in this connection, both because of its refrigerating effect and because of the inhibiting action of the carbon dioxide gas produced. To determine the practicability of this method of food preservation required detailed information concerning the various effects of the gas upon different fruits and vegetables under various conditions.

Since, in preliminary experiments, it was found that the peach and the strawberry were particularly susceptible to injury from carbon dioxide gas, they have been given special consideration. This bulletin reports the results of four years' experimental work on peaches and strawberries, three years' work on dewberries, and tests on other fruits and on vegetables.

REVIEW OF LITERATURE

In 1821 Bérard (*3*)[2] reported that most fruits can be preserved for a certain period by picking a few days before they are ripe and storing in an atmosphere free from oxygen. Peaches, plums, and apricots were held in good condition for 20 to 30 days, and pears and apples for 3 months; but when these periods were exceeded, the fruit failed to ripen upon removal to normal air. Bérard's paper was considered of sufficient importance to be awarded a prize by the French Academy of Sciences, but apparently his new method of food preservation was not put into practical use.

In 1895 Lopriore (*20*) showed that the germination of the spores of *Mucor mucedo* was delayed by the presence of 10 per cent of carbon dioxide in the atmosphere, and that pure carbon dioxide, though producing total inhibition, did not kill the spores even after an exposure of three months.

In 1907 Fulton (*12*) reported experiments in which strawberries were stored in packages and containers having various degrees of tightness. A moderately tight package retarded mold to some extent and was of material value in retaining the bright color and attractive appearance of the fruit, but packages that were sufficiently tight to allow the carbon dioxide of the storage air to reach a concentration of 7 to 10 per cent in a period of six days caused the fruit to develop a bad flavor.

In 1911 Gore and Fairchild (*13*) investigated customs already established in Japan and discovered that the astringency of Japanese persimmons could be removed by three to five days' storage in an atmosphere of carbon dioxide.

In 1913 Hill (*16*) reviewed the literature on gas storage of fruits, raised the question of the effect of holding fruit in a tight refrigerator car without change of air, and pointed out the need of better means of preserving fruit in transit. He reported experiments showing that storage in oxygen-free air results in the spoilage of the flavor and quality of the fruit. Apples stored in hydrogen or nitrogen began to lose their normal color after four or five days. Peaches held in hydrogen, nitrogen, or carbon dioxide for seven days acquired a bad flavor, which was intensified by longer storage. The rate of softening of peaches was greatly decreased by carbon dioxide and to

[2] Italic numbers in parentheses refer to Literature Cited, p. 58.

a considerable extent by hydrogen and nitrogen. Ripe Concord and Catawba grapes respired as rapidly in hydrogen or in nitrogen as in air, and during the first 36 hours of storage this was also true of ripe Duke cherries; but the respiratory activity of green peaches was immediately depressed by storage in either hydrogen or nitrogen.

Bartholomew (*2*) discovered that black-heart of potatoes is caused by a deficiency of oxygen resulting from poor aeration.

Shear, Stevens, and Rudolph (*30*) found that cranberries held in nearly pure carbon dioxide were spoiled by the end of three days, the spoilage becoming evident in a loss of color, in a softening of the flesh, and in the development of a bitter flavor.

Brooks and Cooley (*5*) and Brooks, Cooley, and Fisher (*7*, *8*) found that high percentages of carbon dioxide for a short period or low percentages for a long period delayed the ripening of apples and served as a partial preventive of apple scald, but that there was danger of injuring the flavor of the fruit. Apples were held in pure carbon dioxide for two to six days at 15° C. with no evident injury, but when the period of exposure was extended the fruit developed an alcoholic and nauseating flavor, often followed by a browning and softening of the flesh. Apples were held at 2.5° in an atmosphere containing 2 to 3 per cent carbon dioxide for 20 weeks without injury, and in one instance in 14 per cent carbon dioxide at 15° for several weeks without injury; but attempts to use higher percentages of carbon dioxide over a prolonged period resulted in serious damage to the fruit.

Kidd and West and their associates of the Food Investigation Board of England made an extensive study of the effects of carbon dioxide upon fruit. In the report of the board for 1919 (*14*, *Rpt. 1919*, *pp. 17–18*) it was stated that strawberries could be kept in excellent condition for three to four weeks at 1° to 2° C. either in an atmosphere of oxygen or in one containing reduced amounts of oxygen and moderate amounts of carbon dioxide. Under both of these conditions the growth of fungi was markedly inhibited. In 1920 (*14*, *Rpt. 1920*) an experiment was reported in which the storage life of apples was doubled by holding in gas storage with an average concentration of 14 per cent carbon dioxide and about 8 per cent oxygen.

In a special report of the board in 1923 (*18*) it was pointed out that the losses in oversea shipments from soft scald of apples and brown-heart of apples are due to the poor ventilation in the hold of the ship with the accompanying increase in carbon dioxide and decrease in oxygen. The lowest concentration of carbon dioxide associated experimentally with the occurrence of brown-heart was 13.6 per cent. In a special report in 1927 (*19*), gas storage was shown to give its optimum results at a temperature of about 46.5° F. At that temperature, storage in atmospheres containing 12 per cent of carbon dioxide and 9 per cent of oxygen practically doubled the storage life of apples and was approximately equivalent to air storage at 34°. It was found that gas storage (10 per cent carbon dioxide and 11 per cent oxygen) owed its effectiveness as much to the reduction in the quantity of oxygen as to the increase in carbon dioxide.

These investigators considered that 10 per cent of carbon dioxide might be excessive at temperatures below 42° F., and 11 per cent or less of oxygen dangerous at temperatures above 65°. Diminishing

the oxygen or increasing the carbon dioxide concentration in an atmosphere was found to decrease the respiratory activity in proportion to the effect upon the rate of ripening or aging of the apples. Within the temperature range of susceptibility, they found that the onset of low temperature internal breakdown was accelerated by increasing the concentration of carbon dioxide in the storage air above 5 per cent or by reducing the concentration of oxygen below the normal 21 per cent.

Brown (*9*) found that within very wide limits variation of oxygen pressure had little effect on the germination and growth of fruit-rot organisms, whereas carbon dioxide retarded both germination and growth. The lower the temperature the weaker the nutrient, and, to a less degree, the greater the density at which the spores were sown the more marked became this retarding action. He considered that the greater retardation at lower temperatures could be explained partly on the basis of the greater solubility of carbon dioxide at these temperatures. A concentration of carbon dioxide as great as 20 per cent at ordinary temperatures was found less effective in controlling fungal growth than was a drop in temperature of 10° C. without carbon dioxide. He found that carbon dioxide is always a retarding factor in fungal growth except in cases where alkaline staling takes place, and then it acts as a remedy, making the growth greater where the gas is present.

Experiments were reported in which *Botrytis cinerea*, *Monilia cinerea*, *Rhizopus nigricans*, *Penicillium glaucum*, and other fungi were tested in atmospheres containing different percentages of carbon dioxide. Of the above fungi, *B. cinerea* was inhibited most by the action of the gas and *P. glaucum* least. When inoculated into apples and held at a temperature of either 5° or 15° C., Botrytis was almost completely inhibited by 20 per cent carbon dioxide and greatly checked by 10 per cent. *M. cinerea* was also greatly inhibited, but not so much as Botrytis, while *P. glaucum* was very little affected even by 20 per cent of carbon dioxide.

Bergman (*4*) found that in unventilated cars of strawberries the carbon dioxide did not exceed 2.5 per cent, and he considered this amount not injurious.

Magness and Diehl (*21*) reported that atmospheres containing carbon dioxide in concentrations of 5, 10, 20, and 50 per cent, respectively, with 20 per cent of oxygen, markedly inhibited the softening rate of apples, the retardation in rate of softening varying with the carbon-dioxide concentration. Concentrations of 5 and 10 per cent of carbon dioxide had no appreciable effect upon the flavor of apples. In concentrations of 20 per cent of carbon dioxide, however, there was a slight flavor of fermentation, and fruit held in concentrations of 50 per cent of carbon dioxide was entirely inedible. The experiments were made at 71.5° F. and were continued for a period of from 10 to 11 days.

Stevens and Hawkins (*31*) suggested the possibility that the accumulation of carbon dioxide in the center of a tightly packed car of strawberries might be sufficient to reduce the rot development.

Thomas (*32*) found the percentage of carbon dioxide in the storage air to be a controlling factor in the production of alcohol and acetaldehyde by apples.

Durrell (*10*) reported that concentrations of from 1 to 5 per cent of carbon dioxide stimulated the spores of *Basisporium gallarum* to profuse germination, whereas control cultures failed to germinate.

Fellows (*11*) found that a variation in the carbon dioxide content of the atmosphere between 0.9 and 18 per cent did not greatly affect the growth of *Ophiobolus graminis*. In liquid medium, growth diminished gradually as the oxygen concentration decreased; on solid medium, marked diminution in growth did not occur until the oxygen was below 6 per cent.

Howe (*17*) found that a continuous flow of carbon dioxide into spore suspensions of *Ustilago levis* increased the percentage of germination, apparently as a result of favorable changes in the hydrogen-ion concentration.

Platz, Durrell, and Howe (*26*) reported that atmospheres containing 15 per cent of carbon dioxide were optimum for the germination of chlamydospores of *Ustilago zeae*. They attributed the stimulating effect of the carbon dioxide to the increase in acidity that it produced in the culture medium.

Rippel and Bortels (*27*) found that spores of *Aspergillus niger* germinated very poorly in an atmosphere free from carbon dioxide.

Overholser (*25*) found that the storage life of Fuerte avocados could be considerably extended by holding them in an atmosphere having only 4 to 5 per cent of oxygen and not over 4 or 5 per cent of carbon dioxide. Exposure to an atmosphere containing 20 to 25 per cent of carbon dioxide did not result in objectionable flavors, but prevented normal softening of the flesh even after removal from the experimental conditions.

In another publication, Overholser (*24*) reported that the astringency of Japanese persimmons could be removed by exposure to an atmosphere of carbon dioxide for 12 to 24 hours.

Barker (*1*) found oranges less liable than apples to injury from high concentrations of carbon dioxide. Pronounced injury resulted after five weeks' storage in 25 to 40 per cent carbon dioxide at 34° F., but not at 45° and 55°.

Onslow and Barker (*23*) reported that the alcohol content of oranges severely injured by storage in an atmosphere of high carbon dioxide and low oxygen concentration is significantly higher than that of control oranges.

Thornton (*33*) has shown that the life of cut flowers, especially roses, can be prolonged by holding them in an atmosphere containing a relatively high percentage of carbon dioxide. For a 12-hour period, concentrations of 60 to 80 per cent of carbon dioxide were found desirable, and for a 24-hour period, concentrations of 30 to 50 per cent. In a later publication Thornton (*34*) reports the tolerance of various fruits and vegetables to carbon dioxide.

The effect of carbon dioxide upon bacteria has been investigated from many angles, the results varying widely with the species tested. The literature extends over a period of 50 years and recently has been fully reviewed by Valley (*35*).

PURPOSE OF THE INVESTIGATION

It is evident from the results cited that increases in the carbon dioxide content of the storage air may have a marked effect upon

both fruit and fungi and that this effect will vary with the temperature and also with the organism. Despite the well-established fact that carbon dioxide has a definite inhibiting action upon certain parasitic organisms and also upon the ripening of certain fruits, the investigators who have made the most thorough study of the subject apparently have not felt justified in recommending gas storage for general use, because of the danger of injuring the fruit.

The present studies have been made with the particular purpose of determining the effect of short-period gas storage, such as might be used in car-lot shipments, as a possible substitute for precooling.

METHODS AND APPARATUS

Experiments were carried out at constant temperatures with a constant percentage of carbon dioxide, and also in "pony" refrigerators and in standard refrigerator cars where both the temperature and the percentage of carbon dioxide were continually dropping during a considerable part of the period of the experiment.

EXPERIMENTS AT CONSTANT TEMPERATURES

The constant-temperature experiments were carried out in a series of six refrigerator boxes, each having a capacity of about 1 cubic yard. A different temperature was maintained in each box, thus making it possible to test fruit of the same lot under six different conditions of temperature.

The fruit and the cultures of fungi that were used as controls were held in moist chambers having a capacity of about 1 gallon. Those that were subjected to carbon dioxide were held in wide-mouthed 9-quart bottles. The usual glass stoppers for these bottles were replaced by 2-hole metal stoppers sealed in position with plasticine.

A constant percentage of carbon dioxide was maintained in the test chambers by means of continuous renewal of the storage air. The desired atmosphere was made up outside the storage container and passed rapidly into it until the percentage of carbon dioxide in the exit air had become practically constant. The movement was then slowed down but kept practically continuous throughout the experiment. From 75 to 115 quarts of the gas mixture were passed through each container in a period of 24 hours.

The storage bottles for the prepared atmosphere were outside the refrigerator boxes, and the air from them was passed through coils of copper tubing within the boxes before entering the containers that held the fruit and cultures. This arrangement brought the temperature of the entering air down to approximately that of the refrigerator box before it passed into the container holding the test material.

The prepared atmospheres were always made by mixing carbon dioxide with laboratory air. When the carbon dioxide content of normal air was increased to 10 per cent, the oxygen content was therefore reduced from 21 per cent to 18.9 per cent, and with 25 per cent carbon dioxide added the oxygen was reduced from 21 per cent to 15.75 per cent.

Carbon dioxide determinations were made either by the absorption method or by means of an electrical carbon dioxide indicator.

The desired percentages of carbon dioxide were usually maintained within 1 per cent, but where one-fourth or more of the atmosphere was composed of carbon dioxide the results of the experiment were not discarded if short-period variations of 2 or 3 per cent were found.

EXPERIMENTS IN PONY REFRIGERATORS

Except where otherwise stated, the pony-refrigerator experiments were made in 80-quart pony refrigerators of the type used in Florida strawberry shipments. These refrigerators have two ice pans, one across the top and a vertical one beneath which divides the berries into two separate stacks, each 4 baskets high, 2 baskets wide, and 5 baskets long. Solid carbon dioxide was used as a supplementary refrigerant and as a source of carbon dioxide gas. It was always placed in the top pan and usually on top of a layer of ice. In later experiments it was placed in the four corners of the top pan and partly separated from the pan and from the ice by means of broken berry baskets or similar material.

Complete temperature records were obtained by means of recording thermometers. These were placed in the bottom of the berry baskets and peach carriers and the fruit poured in over them. The results of the recording thermometers were checked by taking the temperature of the fruit at the close of the experiment and in some instances by placing resistance thermometers beside the recording ones during the experiment; the results were usually in close agreement. During the periods of rapid cooling the temperatures as reported probably more closely represent those of the outside tissue of the fruit than either the air temperature or the temperatures in the center of the individual fruits.

Samples of the atmospheres within the refrigerators were obtained by means of copper tubes that passed through the drainage outlet and extended up through the central ice pan and over into the mass of fruit. Carbon dioxide determinations were made as described under constant temperatures (p. 6).

EXPERIMENTS IN STANDARD REFRIGERATOR CARS

In the refrigerator-car experiments, solid carbon dioxide was used as a supplementary refrigerant, as with the pony-refrigerator tests. The cars were iced in the usual manner, and the solid carbon dioxide was placed in the main body of the car on top of the load of fruit, as described in the legends of Figures 8 to 11, 22 to 26, and 29 to 33, inclusive.

Recording thermometers were packed in the baskets and carriers, as described above for the pony refrigerators. They were always placed in the top baskets or carriers of the top crates and in the bottom baskets or carriers of the bottom crates.

Samples of the atmosphere within the car were obtained by means of tubes of copper and rubber extending from various points in the load out through the upper opening of the bunker to the top of the car. Air was drawn out through these tubes by means of an air pump until the percentage of carbon dioxide became constant, and samples were then taken for record analyses. Analyses were made as described under constant temperatures.

STRAWBERRY EXPERIMENTS

In the strawberry experiments special attention was given to the firmness and flavor of the fruit and to the rate of development of the rots.

The firmness of the fruit was determined by pressure tests, made after methods similar to those reported by Magness and Taylor (*22*). The berry was placed on the platform of a dial cigar scale, and the rounded end of an indelible pencil (7 mm in diameter) was brought steadily down upon it and the pressure increased until the berry was punctured. The pressure was read in ounces as registered on the scale at the time of puncturing.

The question of determining whether the flavor of the berries was normal at the close of an experiment was found to be a most difficult matter. A conclusion was reached by having two or more persons test the flavor without knowing the previous treatment. Individuals would sometimes disagree as to whether the treated or control lots had the more desirable taste; but whenever it was evident that the flavor had been changed by exposure to carbon dioxide, it was considered advisable to set this down to the discredit of the treatment, even though some individuals might find nothing objectionable in the change.

The first effect resulting from the carbon dioxide treatments was a slight loss of aroma. With more prolonged or severe treatment, this was followed by a still greater loss of flavor and finally by the development of an odor of fermentation and by other definitely objectionable qualities. The more highly aromatic, highly flavored varieties seemed to show the effect of the carbon dioxide treatment sooner than did those having less aroma.

Practically all the rots that developed without inoculation were due to either Rhizopus or Botrytis, so the inoculation experiments were confined to these two organisms.[3] Rhizopus has been found to cause more decay on strawberries in transit than all other rot organisms combined (*28*). Botrytis probably comes next to Rhizopus as a cause of loss and is of special interest because of the difficulty of controlling it by means of low temperatures.

Botrytis cinerea Auct. and *Rhizopus nigricans* Ehr. were grown on potato-dextrose agar in various concentrations of carbon dioxide and at various temperatures. The agar was poured into Petri plates and allowed to harden. The spores were then pushed into the layer of agar by means of a sterile needle. The depth to which the spores were pushed did not seem to have any effect upon the inhibiting action of the carbon dioxide. The results of the experiments are shown in Table 1.

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[3] The writers are indebted to L. L. Harter for the pure cultures of *Rhizopus nigricans* that were used in their inoculation experiments. The Botrytis cultures used in the inoculation work were obtained from active rots on strawberries and apparently were *B. cinerea*.

TABLE 1.—*Growth of Botrytis cinerea and Rhizopus nigricans on culture media in atmospheres containing various percentages of carbon dioxide*

CO_2 in atmosphere (per cent)	Temperature	Length of treatment [1]	Diameter of colony			
			Botrytis [2]		Rhizopus	
			In CO_2	Control	In CO_2	Control
	° *F.*	*Hours*	*Mm*	*Mm*	*Mm*	*Mm*
10	59	23+164	19	23.2		
10	50	23+164	8.2	10		
10	41	24+163	2.1	2.5		
13	68	22+50	27.5	27.5		
13	59	22+50	20.5	19.5		
13	50	23+49	3.2	4.3		
13	41	23+49	.5	.8		
17	77	22	(25)	(33.5)		
17	68	23	(26.5)	(30)		
17	59	24	(9.5)	(26)		
17	50	46	(23.5)	(33)		
17	41	47	(8)	(21)		
17	32	48	(3.5)	(14)		
19	77	24	(7.3)	(15.4)		
19	68	25	(17)	(19.3)		
19	59	26	(3.2)	(13.7)		
19	50	48	(3.9)	(11.5)		
19	41	48	(2.6)	(8.5)		
19	32	48	(.8)	(3.8)		
23	77	72	2	55		
23	68	72	5	40	40	95
23	59	72	0	30	0	32
23	50	72	0	6	0	2
23	41	100	0	4		
37	77	26	0	5	30	95
37	68	26	0	4	0	12
37	59	50	0	12	0	30
37	50	98	0	13	0	21
46	77	24	0	7.3		
46	68	24	0	2.5		
46	59	22+23	0	5		
46	50	26+45	.8	2.5		

[1] Where two numbers are used, the first shows the hours of exposure to carbon dioxide and the second the additional hours at the given temperature before the record was taken.

[2] Numbers in parentheses show the increase in diameter of colonies that were large enough to be measured before the experiment was started. In all other cases the inoculations were made at the time the experiment was started.

STRAWBERRIES AT CONSTANT TEMPERATURES

Strawberries also were held in various percentages of carbon dioxide at various constant temperatures. From 8 to 15 berries were used under each condition tested. They were selected individually and with great care, in order that those to be compared under different conditions should be as nearly alike as possible in maturity, firmness, size, color, and freedom from injuries. The Rhizopus inoculations were made by pushing the spores into the flesh of the strawberries in the usual manner. Botrytis inoculations that were made in the same way caused no evident development during the period of the experiment, but it was found that by cutting 4-millimeter disks of mycelium and agar from Petri-dish cultures and placing them on the berries a definite rot and a measurable growth of mycelium could be secured. The Botrytis growth measurements, as reported in Table 2, indicate the increase in diameter of these mycelial disks. The pressure tests were made as described on page 8 and the carbon dioxide atmospheres were prepared as described under Methods and Apparatus (p. 6). The results are reported in Table 2.

TABLE 2.—*Effects of different percentages of carbon dioxide on strawberries at various constant temperatures*

Variety	Date	CO_2 in atmosphere	Temperature	Length of CO_2 treatment	Pressure test			Flavor		Development of rots			
					Before CO_2 treatment	After CO_2 treatment	Control	After CO_2 treatment	Control	Increase in diameter of Botrytis colony		Infections from Rhizopus inoculations	
										After CO_2 treatment	Control	After CO_2 treatment	Control
		Per cent	°*F.*	*Hours*	*Ounces*	*Ounces*	*Ounces*			*Mm*	*Mm*	*Per cent*	*Per cent*
U. S. D. A. No. 450	June 3, 1929	10	68	22		7.8	7.3	Slightly flat	Good				
Do	do	10	59	22		7.7	7.6	do	do				
Do	do	10	50	23		7.7	6	Less flavor	do				
Do	do	10	41	24		9.9	7.3	do	do				
Do	do	10	32	25		10.7	6.8	Good	do				
U. S. D. A. No. 25	May 20, 1929	13	68	22		9.5	8.5	do	do				
Do	do	13	59	22		9.3	6.6	do	do				
Do	do	13	50	23		9.4	7.9	do	do				
Do	do	13	41	23		9.5	8.9	do	do				
Missionary and Dunlap	May 22, 1930	17	77	22				do	do				
Do	do	17	68	23				Less aroma	do				
Do	do	17	59	24				do	do				
Do	do	17	50	46				Good	do				
Do	do	17	41	47				do	do				
Do	do	17	32	48				do	do				
Missionary	Mar. 13, 1930	19	77	24				do	do				
Do	do	19	68	25				do	do				
Do	do	19	59	26				do	do				
Do	do	19	50	26				do	do				
Do	do	19	41	26				do	do				
Do	do	19	32	26				do	do				
Do	Mar. 19, 1930	20	77	24				Off	Poor				
Do	do	20	68	26				Fair	do				
Do	do	20	59	27				do	Off				
Do	do	20	50	47				Poor	Fair				
Do	do	20	41	47				Fair	do				
Do	do	20	32	49				Good	Good				
Do	Apr. 9, 1928	23	77	48	9.8	10.1	5.7	do	Poor			0	67
Klondike-Howard 17 (cross)	May 31, 1928	23	77	45	9.3	9.1	4.1	Distinctly off	Good	0	15		
Missionary	Apr. 9, 1928	[2]23	68	48	9.8	9.3	11.6	Good	do			0	65
Klondike-Howard 17 (cross)	May 31, 1928	23	68	45	9.3	9.8	7	Distinctly off	do	0	12		
Heflin	May 25, 1928	23	68	72	8.3			Insipid	do	11	20		
Aroma	May 17, 1929	23	68	22				Less aroma	do				

U. S. D. A. Nos. 450 and 668	May 27, 1929	23	68	22		12.8	12	do	do			
Missionary	Apr. 9, 1928	[2] 23	59	96	9.8	13.2	8.2	Good	do			0	0
Klondike-Howard 17 (cross)	May 31, 1928	23	59	47	9.3	9.3	9.1	Distinctly off	do	0	8		
Heflin	May 25, 1928	23	59	72	8.3	12.6	7.9	Fair	do	4	14		
Aroma	May 17, 1929	23	59	22				Good	do				
U. S. D. A. Nos. 450 and 668	May 27, 1929	23	59	22		12.5	13.3	do	do				
Missionary	Apr. 9, 1928	23	50	120	9.8	11.8	8	Slightly off	do				
Klondike-Howard 17 (cross)	May 31, 1928	23	50	47	9.3	10.5	9.4	Lacking flavor	do	6	7.5		
Heflin	May 25, 1928	23	50	73	8.3	9.2	10.4	Good	do	0	6		
Aroma	May 17, 1929	23	50	26				do	do				
U. S. D. A. Nos. 450 and 668	May 27, 1929	23	50	23		13.4	12.7	do	do				
Missionary	Apr. 9, 1928	23	41	124	9.8	13	12.7	do	do				
Klondike-Howard 17 (cross)	May 31, 1928	23	41	92	9.3	12.7	11.4	do [1]	do	0	6.5		
Heflin	May 25, 1928	23	41	100	8.3	13	9.3	Off a trace	do	4	8		
Aroma	May 17, 1929	23	41	26				Good	do				
U. S. D. A. Nos. 450 and 668	May 27, 1929	23	41	24		11.3	10.4	do	do				
Missionary	Apr. 9, 1928	23	36.5	124	9.8	15.4	11.8	do [1]	do				
Klondike-Howard 17 (cross)	May 31, 1928	23	36.5	92	9.3	12.5	9.5	do [1]	do	0	7.6		
Heflin	May 25, 1928	23	36.5	100	8.3	13	10.7	Off a trace [1]	do	4	9		
U. S. D. A. Nos. 450 and 668	May 27, 1929	23	32	25		14.3	9.7	Good	do				
Missionary	Apr. 17, 1928	37	77	24	9.8	11.2	7	Fair	Fair	0	3.5		
Do	Apr. 18, 1928	37	77	24	9.7	11.3	10.2	do	do	0	4.5		
Do	Apr. 23, 1928	[3] 37	77	26	12.2	10.5	5.9	Good	Good	0	3.7		
Do	Apr. 17, 1928	37	68	24	9.8	10.1	10.7	Fair	Fair	0	7.5		
Do	Apr. 18, 1928	37	68	24	9.7	10.2	9.3	do	do	0	4		
Do	Apr. 23, 1928	[3] 37	68	26	12.2	10.5	9.2	Good	Good	0	4.5	0	50
Do	Apr. 18, 1928	37	59	48	9.7	11.9	8.4	Fair	Fair	0	9		
Do	Apr. 23, 1928	[3] 37	59	50	12.2	14.5	8.3	Good	Good	0	8		
Do	Apr. 18, 1928	37	50	72	9.7	12.3	11.6	do	do	0	8		
Do	Apr. 23, 1928	[3] 37	50	98	12.2	13.6	14.9	Fair	Fair	0	6		
Do	Apr. 18, 1928	37	41	140	9.7	13	11.3	Good	Good	0	1.5		
Do	Apr. 23, 1928	37	41	100	12.2	13.6	14	Fair [1]	Fair	0	5		
Do	Apr. 18, 1928	37	36.5	140	9.7	11.4	12.3	Slightly off	Good	0	3		
Do	Apr. 23, 1928	37	36.5	100	12.2	15.8	14.8	Good [1]	do	0	3		
Do	Mar. 27, 1928	46	77	24	12.8	12.1	9.9	do	do				
Do	Apr. 3, 1928	46	77	24	9.1	11.3	4.6	Poor	Fair	0	4		
Do	Mar. 19, 1928	46	68	24	8.6	10.2	9	Good	Good	0	1.1		
Do	Mar. 27, 1928	46	68	24	12.8	11.2	11.2	do	do				
Do	Apr. 3, 1928	46	68	24	9.1	9	8.3	Slightly off	do	0	4		
Do	Mar. 27, 1928	46	59	48	12.8	12.9	12.3	Good	do				
Do	Apr. 3, 1928	46	59	27	9.1	11.9	10.2	Slightly off	do	0	2		
Do	Mar. 27, 1928	46	50	53	12.8	12.4	10.7	Good	do				
Do	Apr. 3, 1928	46	50	51	9.1	10.8	11.8	do	do	0	4		
Do	Mar. 27, 1928	46	41	53	12.8	13.4	13.9	do	do				
Do	Apr. 3, 1928	46	41	72	9.1	11.3	11.3	do	do	0	1		
Do	do	46	36.5	72	9.1	10.5	9.9	do [1]	do	0	0		
Do	Mar. 19, 1928	[4] 46–23	59	41	8.6	12.3	10.1	do	do	0	1.6		
Do	do	[4] 46–23	50	41	8.6	11.6	11.2	do	do	0	4		
Do	do	[4] 46–23	41	41	8.6	10.8	11.6	do	do	0	2.3		

[1] This jar had no change of atmosphere during the experiment.
[2] During the 15 hours following the first 6 hours, 32 per cent instead of 23 per cent.
[3] During the 15 hours following the first 6 hours, 63 per cent instead of 37 per cent.
[4] 46 per cent for 24 hours followed by 23 per cent for 17 hours.

Table 1 shows that atmospheres containing 10 to 13 per cent of carbon dioxide had little inhibiting effect upon Botrytis grown on culture media, whereas atmospheres with 17 to 19 per cent of carbon dioxide had a checking effect approximately equivalent to that of a drop of 18° F. in temperature. With 23 per cent of carbon dioxide both Botrytis and Rhizopus were almost completely inhibited in most instances both on the culture media and on the fruit. (Tables 1 and 2.) On culture media Botrytis was more completely inhibited than was Rhizopus, whereas on the fruit the reverse condition held. With 37 per cent of carbon dioxide Botrytis was held completely in check at all temperatures, and with one exception this was also true of Rhizopus.

The records on resistance to pressure at the close of the experiment were taken while the fruit was still cool. This, no doubt, accounts for some of the instances in which the pressure was higher at the close of the experiment than at the beginning (*15*). Atmospheres containing 10 to 13 per cent of carbon dioxide did not seem to have any pronounced checking effect upon the softening of the fruit, but those containing 23 per cent or more of carbon dioxide largely, if not entirely, prevented softening at all temperatures. At the higher temperatures there was usually a marked difference in firmness between the treated and the control fruit at the end of the experiment. It was found that this difference was maintained for a considerable time after the removal of the fruit to the same atmospheric conditions.

The small number of berries included in the tests and their wide individual variation made the determination of difference in flavor particularly difficult and the results, perhaps, somewhat unreliable. It will be noted that in the experiments carried out in 1929 and 1930 injury was obtained with lower percentages of carbon dioxide and with shorter treatments than in the experiments of 1928. In some instances this may have been due to the variety of berries, but the writers are convinced that as the work progressed they developed a much more critical sense of taste and that this accounts partly for the inconsistent results. In the experiments of 1928 no injury to flavor was detected after subjecting Missionary berries to atmospheres containing 23 per cent of carbon dioxide for 48 hours at 77° or 68° F., 96 hours at 59°, or 124 hours at 41°; and no injury was detected after exposure to 37 per cent of carbon dioxide for 24 hours at 77° or 68°, 48 hours at 59°, 72 hours at 50°, or 100 hours at 41°. In the experiments of 1930 a reduction in aroma was noted in Missionary and Dunlap berries after exposure to 17 per cent of carbon dioxide at 68° for 23 hours, and in the experiments of 1929 a similar change in U. S. D. A. No. 450 was noted after exposure to 10 per cent of carbon dioxide for 23 to 24 hours at 50° and 41°. The writers believe that the results of 1928 could be duplicated if individuals of average taste discrimination were the judges, but in light of later experiments they are of the opinion that in some instances there may have been a loss of flavor in the 1928 experiments that was not detected at the time the experiments were made.

The varieties with a relatively high aroma were the most susceptible to injury from carbon dioxide. The Heflin, U. S. D. A. No. 450, and Aroma were more susceptible than were Missionary and Klondike.

Strawberries showed a greater endurance of carbon dioxide treatments at lower temperatures than at higher ones. The differences were fairly consistent with the usual physiological responses to temperature.

STRAWBERRIES IN PONY REFRIGERATORS

The pony-refrigerator experiments were carried out as described under Methods and Apparatus (p. 7) and the inoculations were made as described under Strawberries at Constant Temperatures (p. 9). In addition to the Petri-dish and disk inoculations, berries that were already rotten from Botrytis were placed at various points in the baskets, and at the close of the experiment a record was taken of the number of berries infected by contact with the rotten fruit.

The result of the various pony-refrigerator experiments are shown in Table 3 and in Figures 1 to 7, inclusive.

TABLE 3.—*Condition of strawberries held in pony refrigerators with solid carbon dioxide as a supplementary refrigerant*

Figure reference[1]	Ice		Solid CO_2 used	Pressure test upon removal	Flavor upon removal	Berries frozen	Botrytis rot				Rhizopus on uninoculated berries
	At beginning	At end					Diameter of Petri-dish colonies	Increase in diameter of disks	Average infections from one rotten berry	On uninoculated berries	
Fig. 1:	*Lbs.*	*Lbs.*	*Lbs.*	*Oz.*		*Per cent*	*Mm*	*Mm*	*Number*	*Per cent*	*Per cent*
a	135	0	0	9.1	Good	0		8	1.8	11.7	25.4
b	105	15	30	12.5	do	4		3	.3	6	10.8
c	90	16	45	12.1	Reduced aroma	16		4	.2	3.6	8
d	75	20	60	12.2	do	29		3	.1	2.7	10
Fig. 2:											
a	135	0	0	9.1	Good	0	5.5		3.2	24.9	5.4
b	125	0	10	10.2	Very good	0	2.2		2.3	24.8	2.8
c	120	1	15	9.9	do	2	0		1.7	18.6	3.6
d	110	0	25	10.4	Reduced aroma	6	1		1.8	22.8	2.5
Fig. 3:											
a	135	16	0	8.9	Fair	0			2.5	2	27.2
b	120	32	15	9.4	do	.5			.5	1.4	34.2
c	110	40	25	8.7	do	2.3			1.8	1.2	31
d	100	47	35	11.4	do	6.7			.6	1.2	27.8
Fig. 4:											
a	144	36	0	8.7	Good	0	2		1.3	.4	17.6
b	119	42	15	11.1	Reduced aroma	6	0		0	.3	12
c	119	23	20	11.9	Off taste	9	0		0	.4	9.6
d	110	44	30	13.2	Bad	9	0		0	0	8.8
Fig. 5:											
a	183	50	0	8.3	Good	0	27			2.9	47.7
b	156	67	16	9.6	Reduced aroma	0	11.5			.5	10.1
c	144	73	18	11	do	0	12			0	9
Fig. 6:											
a	161	62	0	9.7	Good	0				12	
b	145	66	15	14.6	do	.5				8.9	
c	101	67	35	15.3	Off flavor[2]	1				7.6	
Fig. 7:											
a	163	22	0	7.3	Good	0	5.8			42.9	
b	147	23	7	9.6	do	0	3.6			21.7	
c	94	37	12	8.6	do	0	3.6			32.1	

[1] For data on variety, CO_2, temperature, and length of treatment, see Figs. 1 to 7, inclusive.
[2] After 3 days at 50° F. the objectionable flavor had disappeared.

In most cases two recording thermometers were used in each refrigerator, thus giving opportunity for comparing the temperatures in different parts of the same container. In the control the top layer was sometimes a few degrees warmer than the bottom, es-

pecially at the beginning and near the close of the experiment. The middle layers were always warmer than the top layer, and the fruit in the corners was always warmer than that in the center, near the vertical pan.

Where solid carbon dioxide was used, the top layer of fruit was usually as cold as, and sometimes colder than, the bottom layer; and where the solid carbon dioxide was placed in the corners of the top refrigerating pan, the difference in temperature between the fruit in the center and that in the corners was much less than in the control.

When freezing injury resulted from the use of large amounts of solid carbon dioxide it was mostly in the top layer and usually worse in the center than in the corners.

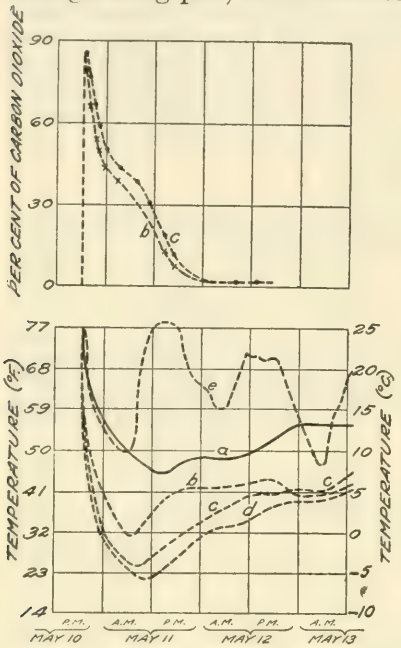

FIGURE 1.—Carbon dioxide curves and temperature curves in an experiment with Klondike strawberries in pony refrigerators, Chadbourn, N. C., May 10 to 13, 1928: *a*, Control refrigerator with 135 pounds of ice; *b*, refrigerator with 105 pounds of ice and 30 pounds of solid CO_2; *c*, refrigerator with 90 pounds of ice and 45 pounds of solid CO_2; *d*, refrigerator with 75 pounds of ice and 60 pounds of solid CO_2 (no record of CO_2 percentage); *e*, outside temperature. The thermographs were in the top layer of baskets

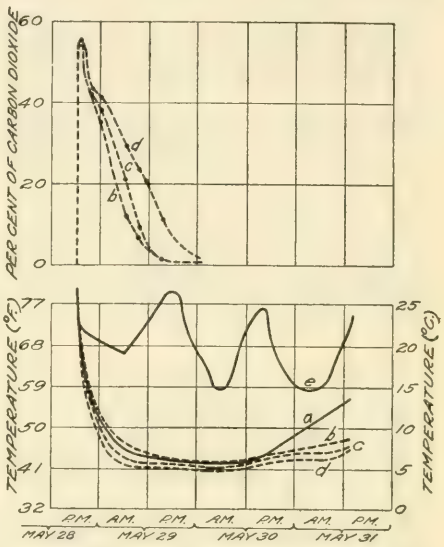

FIGURE 2.—Carbon dioxide curves and temperature curves in an experiment with Klondike strawberries in pony refrigerators, Chadbourn, N. C., May 28 to 31, 1928: *a*, Control refrigerator with 135 pounds of ice; *b*, refrigerator with 125 pounds of ice and 10 pounds of solid CO_2; *c*, refrigerator with 120 pounds of ice and 15 pounds of solid CO_2; *d*, refrigerator with 110 pounds of ice and 25 pounds of solid CO_2; *e*, outside temperature. The temperatures shown are the average of records from the top and bottom layers of baskets

Despite the fact that the use of solid carbon dioxide sometimes resulted in freezing injury, the temperature curves of Figures 1 to 7 do not indicate that it greatly lowered the average temperature in the boxes. However, by the proper placing of the solid carbon dioxide it was found possible to bring about a significant lowering of the temperature in the warmer parts of the refrigerator without causing freezing injury in the colder parts.

The most significant differences in temperature came at the close of the experiments in cases where the outside temperature was high or the storage period prolonged. In such cases the temperature of the

control rose earlier and more rapidly than that of the refrigerator containing solid carbon dioxide. A reason for this is found in the amount of ice left in the different boxes at the close of the experiments, as shown in the third column of Table 3. The carbon dioxide gas apparently had an insulating or blanketing effect that tended to check the action of the refrigerants, thus limiting the initial rate of cooling but extending the possible period of refrigeration.

The carbon dioxide content of the air in the control refrigerator was tested at various times and usually found to be 1 to 1½ per cent.

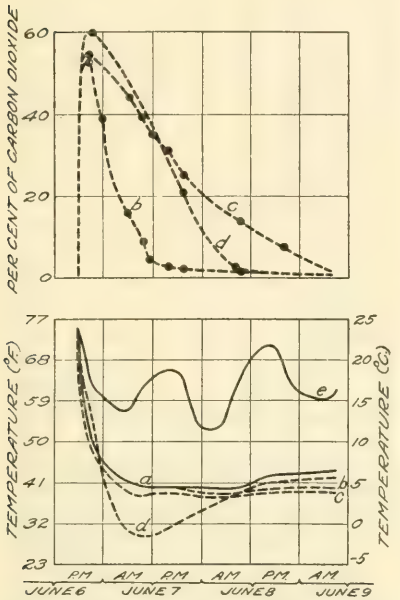

FIGURE 3.—Carbon dioxide curves and temperature curves in an experiment with strawberries from United States Department of Agriculture breeding plots at Glenn Dale, Md., in pony refrigerators, June 6 to 9, 1928. The records were made on crosses Nos. 122 and 197: *a*, Control refrigerator with 135 pounds of ice; *b*, refrigerator with 120 pounds of ice and 15 pounds of solid CO_2; *c*, refrigerator with 110 pounds of ice and 25 pounds of solid CO_2; *d*, refrigerator with 100 pounds of ice and 35 pounds of solid CO_2; *e*, outside temperature. The thermographs were in the top layer of baskets

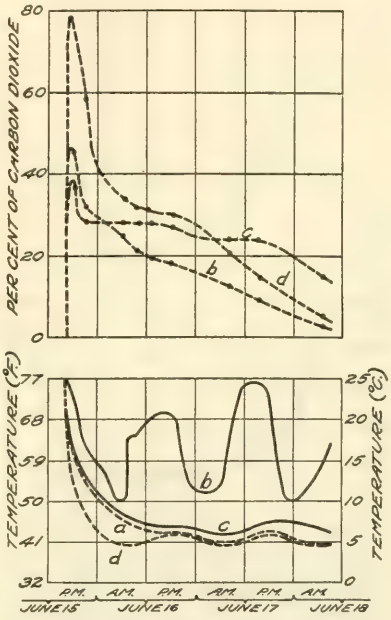

FIGURE 4.—Carbon dioxide curves and temperature curves in an experiment with strawberries from United States Department of Agriculture breeding plots at Glenn Dale, Md., in pony refrigerators, June 15 to 18, 1928: *a*, Control refrigerator with 144 pounds of ice; *b*, refrigerator with 119 pounds of ice and 15 pounds of solid CO_2 (no temperature record); *c*, refrigerator with 119 pounds of ice and 20 pounds of solid CO_2; *d*, refrigerator with 110 pounds of ice and 30 pounds of solid CO_2; *e*, outside temperature. The thermographs were in the top layer of baskets

The percentage of carbon dioxide gas in the refrigerators in which solid carbon dioxide was used is shown in the upper portions of Figures 1 to 7. Little difference was found in the carbon dioxide content of the air in the different parts of the same refrigerator. The records as reported are based on air samples taken from near the center of the refrigerator.

As would be expected, there was a fairly close relationship between the amount of solid carbon dioxide used and the percentage of carbon dioxide gas in the air. There is, however, considerable variation in the character of the curves, as shown in Figures 1 to 7. Part of this variation was due to the fact that the solid carbon

dioxide was not always broken up to the same degree of fineness, and also that in a few cases free downward movement of the gas was somewhat checked by the containers in which the solid carbon dioxide was held.

It will be seen that the percentage of carbon dioxide gas mounted rapidly as soon as the refrigerators were closed; a maximum was often reached within half an hour, followed by a rapid drop a few hours later. During the first 6 to 10 hours the carbon dioxide

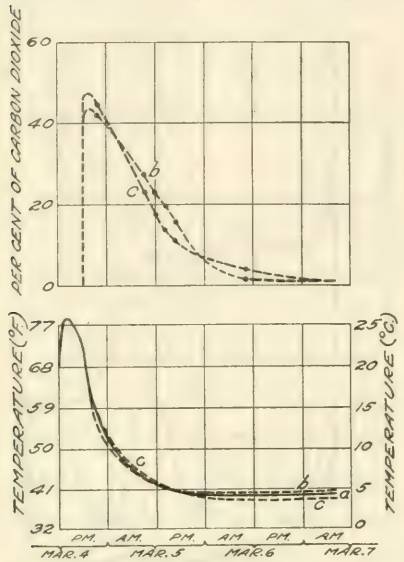

FIGURE 5.—Carbon dioxide curves and temperature curves in an experiment with Missionary strawberries in pony refrigerators, Plant City, Fla., March 4 to 7, 1929: *a*, Control refrigerator with 183 pounds of ice; *b*, refrigerator with 156 pounds of ice and 16 pounds of solid CO_2; *c*, refrigerator with 144 pounds of ice and 18 pounds of solid CO_2. The refrigerator in *c*, had better insulation than the others, held 75 quarts of berries instead of 80 quarts, and had ice pans on the side instead of on top and in the center. On March 4 the maximum outside temperature was 87° F., the minimum 66°; on March 5 the maximum was 74°, the minimum 54°; and on March 6 the maximum was 69° and the minimum 43°. The berries used in the experiment were from the experimental plots of A. N. Brooks

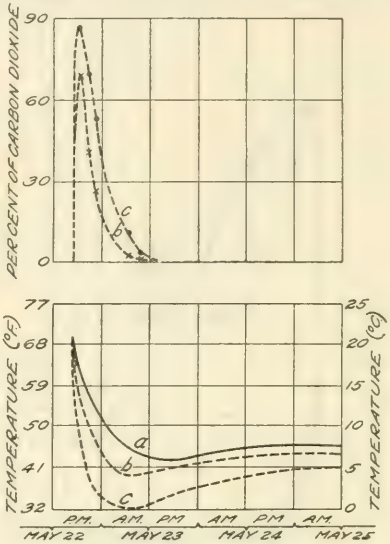

FIGURE 6.—Carbon dioxide curves and temperature curves in an experiment with strawberries from the United States Department of Agriculture breeding plots at Glenn Dale, Md., in pony refrigerators, May 22 to 25, 1929. The records were made on crosses Nos. 25 and 620 and on Missionary strawberries: *a*, Control refrigerator with 161 pounds of ice; *b*, refrigerator with 145 pounds of ice and 15 pounds of solid CO_2; *c*, refrigerator with 101 pounds of ice and 35 pounds of solid CO_2. The refrigerator in *c* had better insulation than the others and lacked the vertical ice pan described for the standard refrigeration. The temperatures shown are the average of records from the top and bottom layers of baskets. On May 22 the maximum outside temperature was 68° F., the minimum 46°; on May 23 the maximum was 75°, the minimum 45°; and on May 24 the maximum was 77°, the minimum 60°

content was usually 40 to 80 per cent, but by the end of 24 hours it had usually dropped below 10 per cent, and often to 1 or 2 per cent.

In cases where the carbon dioxide content of the atmosphere had fallen to 25 per cent within 12 hours and to 10 per cent within 24 hours, no injury to the flavor of the fruit could be detected; but in most instances where these percentages were exceeded there was either a loss of flavor or, in the more extreme cases, a definitely disagreeable flavor. In the three instances where 12 pounds or less of solid carbon dioxide was used and in three of the five instances where

15 or 16 pounds was used, the flavor of the fruit was not affected. Rapid cooling seemed to decrease the probability of injury; this is in agreement with the differences in results at various constant temperatures, as shown in Table 2.

Sample lots of fruit, after removal from the various refrigerators, were held for later tests of flavor. In a few instances berries lacking in aroma upon removal regained their normal flavor, but in most instances they failed to do so.

Increasing the carbon dioxide content of the storage air had a very significant effect on the firmness of the fruit. Disregarding the results of the experiments in which the flavor of the berries was affected, the average resistance to pressure at the end of the experiments was 8.7 ounces in the control refrigerators and 11.2 ounces in the refrigerators containing solid carbon dioxide. There was usually a corresponding contrast in the number of extremely soft berries.

The effect of the solid carbon dioxide upon the rot organisms was equally significant. Excluding the instances in which the flavor of the fruit was affected, the average growth of the rot organisms was reduced more than 50 per cent in all the inoculation tests; the average growth of the Botrytis rot on the uninoculated fruit was reduced more than 30 per cent, and that of the Rhizopus rot on the uninoculated fruit was reduced more than 50 per cent. Apparently these reductions were largely due to differences in the carbon dioxide of the atmosphere rather than to differences in temperature.

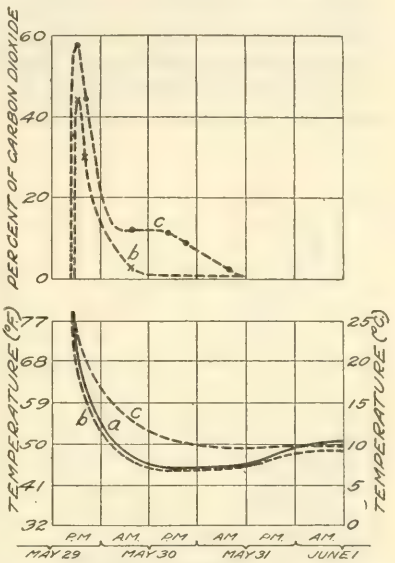

FIGURE 7.—Carbon dioxide curves and temperature curves in an experiment with strawberries from the United States Department of Agriculture breeding plots in Glenn Dale, Md., in pony refrigerators, May 29 to June 1, 1929: *a*, Control refrigerator with 163 pounds of ice; *b*, refrigerator with 147 pounds of ice and 7 pounds of solid CO_2; *c*, refrigerator with 94 pounds of ice and 12 pounds of solid CO_2. The refrigerator in *c* was the same as described under *c* of Figure 6. The temperatures shown are the average of records from the top and bottom layers of baskets. On May 29 the maximum outside temperature was 83° F., the minimum 70°; on May 30 the maximum was 85°, the minimum 67°; and on May 31 the maximum was 92°, the minimum 69°

STRAWBERRIES IN REFRIGERATOR CARS

In other experiments solid carbon dioxide was used in car-lot shipments. The method of handling the material is described under Methods and Apparatus (p. 7). The methods of inoculation were the same as those used in the pony-refrigerator experiments (p. 3). A record was included of the rot development on the uninoculated fruit.

The temperature and carbon dioxide records are shown in Figures 8 to 11, inclusive, and the icing records and time and place of shipment are given in the legends to these figures.

The use of solid carbon dioxide tended to lessen the melting of the ice. (Figs. 10 and 11.) Apparently this was due largely to the insulating or blanketing effect of the carbon dioxide gas, since the differences in temperature between the cars were not great enough to cause any decided difference in the melting of ice.

The temperature curves show that the top of the load cooled somewhat more rapidly in the test cars than it did in the controls. In some instances this was true of the bottom center of the cars also, but the bottom next to the bunker was usually as warm in the carbon dioxide car as in the control car. There was thus a slight tendency to equalize the temperatures of the different parts of the load. This may have been at least partly due to the fact that the solid carbon dioxide was placed directly above the load. There is indication in some of the curves that

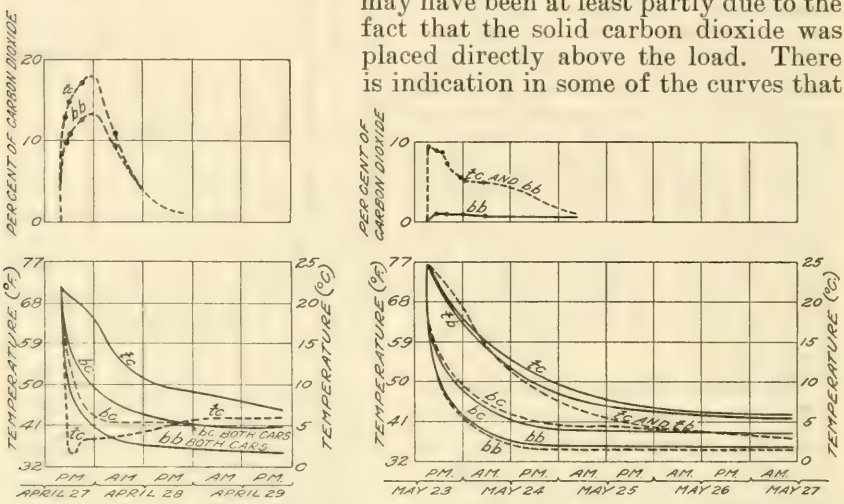

FIGURE 8.—Carbon dioxide curves and temperature curves in an experiment with Klondike strawberries shipped in standard refrigerator cars from Chadbourn, N. C., April 27, 1927. The broken lines give the records for the test car, the solid lines the records for the control car; *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. 319 pounds of solid CO_2 was used. It was held in a box in the center of the car about 4 inches above the top of the load. The recording thermometer for the top center of the car was beneath this box

FIGURE 9.—Carbon dioxide curves and temperature curves in an experiment with Heflin strawberries shipped in standard refrigerator cars from Onley, Va., May 23, 1927. The broken lines give the records for the test car, the solid lines the records for the control car; *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. 283 pounds of solid CO_2 was used in the test car. It was held about 6 inches above the load in three boxes, one in the center of the car and one in each end at a distance of about 5 feet from the bunker. Care was taken that the thermometers should not be located under the solid CO_2. Each car contained 224 crates of berries

the use of the solid carbon dioxide in the main body of the car sometimes caused the air movement in the bunker to be reversed for short periods, making the current pass upward and out at the top instead of moving downward and out at the bottom.

The carbon dioxide content of the air mounted rapidly in the test car as soon as the car was closed, reaching or nearing its maximum in one or two hours. In the experiment reported in Figure 9 the carbon dioxide remained below 10 per cent; in that shown in Figure 8 it stayed near 15 per cent for several hours and above 10 per cent for about 12 hours; in Figure 11 it reached a maximum of 20 per cent and remained above 10 per cent for about 18 hours; in Figure 10 it reached a maximum of 30 per cent and stood above 10 per cent for 15 to 25 hours, depending on the location in the car.

In the experiments reported in Figures 8 and 10 there was a greater concentration of carbon dioxide in the top center of the car than at other points, but in the experiments of Figures 9 and 11 this does not appear to have been the case.

The percentage of carbon dioxide gas was affected by the tightness of the car as well as by the amount of solid carbon dioxide used. The amounts of solid carbon dioxide reported in the legends for Figures 10 and 11 probably would not be advisable with strawberries loaded in new cars or in cars that had recently been reconditioned.

A number of analyses of the carbon dioxide content of the air in the control cars were made, and it was usually found to be below 1 per cent and never above 1.75 per cent.

The fruit in all the cars was critically tested at destination for anything unusual in taste, but nothing could be detected. In some instances there was a suggestion of less maturity in the fruit of the test car, but this seemed to be a real maturity difference as shown in the firmness of the fruit rather than a definite reduction in aroma as mentioned in the discussion of the pony refrigerator experiments (p. 17).

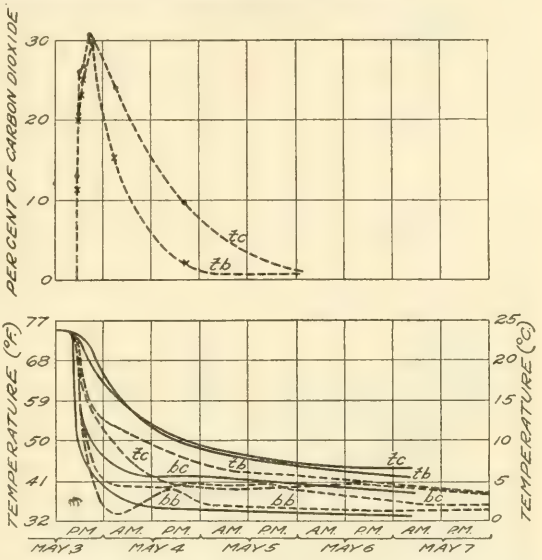

FIGURE 10.—Carbon dioxide curves and temperature curves in an experiment with Klondike strawberries shipped in refrigerator cars from Chadburn, N. C., May 3, 1928. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. 798 pounds of solid CO_2 was used in the test car. It was held on a scaffold in the center of the car about 14 inches above the load. This car also had 2 per cent of salt added at the shipping point. The control car required a total of 390 pounds more ice at the reicing stations than did the carbon dioxide car. Each car contained 224 crates of berries

For the records on firmness and rots, as shown in Table 4, two or more crates of uniformly graded berries were selected at the shipping point, and the 64 or more baskets from these crates were substituted for other baskets in different parts of the car. At destination these baskets were reassembled for note taking. This arrangement made it possible to obtain a record on comparable lots of berries located in the different parts of the two cars. In the experiments of Figures 8, 10, and 11 the fruit of the test crates at the time of shipping was distinctly riper and softer than was the average for the load. The results, therefore, while comparable, show the condition of the worst of the berries of the regular shipment upon arrival at destination rather than the average condition of the load. In the experiment of Figure 9 the results, as shown in Table 4, give a good picture of the general condition of the fruit in the two cars. In this instance all the fruit was somewhat soft and overripe at the time of loading, and the shipment was on the road practically four days.

TABLE 4.—*Condition of strawberries after shipment in standard refrigerator cars with solid carbon dioxide as a supplementary refrigerant*

Figure reference[1]	Location in car	Flavor upon removal from—		Pressure test upon removal from—		Soft and overripe berries upon removal from—		Botrytis rot						Rhizopus rot in uninoculated berries from—		Total rot in uninoculated berries from—		Remarks
								From disk inoculations on berries from—		Average infections from one rotten berry in—		In uninoculated berries from—						
		Test car	Control car	Test car	Control car	Test car	Control car	Test car	Control car	Test car	Control car	Test car	Control car	Test car	Control car	Test car	Control car	
				Oz.	*Oz.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*No.*	*No.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
Fig. 8	Top center	Good	Good			15.8	44.8									1.3	26.8	Record taken 12 hours after removal from cars.
	Top bunker	do	do			30.7	18.8									0	64.3	
	Average top of car					23.3	31.8									.6	45.6	
	Bottom center	do	do			25.7	37.9									3.5	16.4	
	Bottom bunker	do	do			12.8	35.6									1.6	19.8	
	Average bottom of car.					19.3	36.8									2.6	18.1	
	Average for car					21.3	34.3									1.6	31.8	
Fig. 9	Top center	do	do	4.6	3.7	34.2	53.6									3.9	20.8	Record taken immediately after opening of cars.
	Top bunker	do	do	3.8	3.4	45.5	38.8									12.2	28.6	
	Average top of car			4.2	3.6	39.9	46.2									8.1	24.7	
	Bottom center	do	do	5	2.8	34.4	28.9									4.2	3.2	
	Bottom bunker	do	do	4.8	3.1	27.5	46.6									2.1	4.6	
	Average bottom of car.			4.9	3	31	37.8									3.2	3.9	
	Average for car			4.6	3.3	35.4	42									5.6	14.3	
Fig. 10	Top center	do	do	12	8.5			20	0	0.5	4.3	5	12.6	22.1	31.2	27.1	43.8	The treated carload was opened 19 hours later than the control. Record taken immediately after opening in each lot.
	Top bunker	do	do	13.1	9.7			0	100	3.1	4.8	12.9	14.9	15.1	22	28	36.9	
	Average top of car			12.6	9.1			10	50	1.8	4.6	9	13.8	18.6	26.6	27.6	40.4	
	Bottom center	do	do	12.7	9.7			20	60	.7	5.3	1.4	17.1	12.3	11.8	13.7	28.9	
	Bottom bunker	do	do	15.5	9.1			20	60	.5	2.8	1.3	11.5	10.4	11.9	11.7	23.4	
	Average bottom of car.			14.1	9.4			20	60	.6	4.1	1.4	14.3	11.4	11.9	12.7	26.2	
	Average for car			13.3	9.3			15	55	1.2	4.3	5.2	14	15	19.2	20.2	33.3	
Fig. 11	Top center	do	do	12.3	11.3					.7	3	.5	3.4	20.5	24.3	21	27.7	Record taken immediately after opening of cars. The top bunker record for the carbon dioxide car was from third layer; that for control car from second layer.
	Top bunker	do	do	12.1	10.7					1.8	2.8	1.1	0	25.4	33.9	26.5	33.9	
	Average top of car			12.2	11					1.3	2.9	.8	1.7	23.0	29.1	23.8	30.8	
	Bottom center	do	do	11.1	11.1					.3	1.5	.4	1.2	14.6	15	15	16.2	
	Bottom bunker	do	do	13.5	9.5					.2	2.7	.2	.4	18.1	18	18.3	18.4	
	Average bottom of car.			12.3	10.3					.3	2.1	.3	.8	16.4	16.5	16.7	17.3	
	Average for car			12.3	10.7					.8	2.5	.6	1.3	19.7	22.8	20.3	24.1	
Average	Top of car			9.7	7.9	31.6	39			1.6	3.8	4.9	7.8	20.8	27.9	15.0	35.4	
	Bottom of car			10.4	7.6	25.2	37.3			.5	3.1	.9	7.6	13.9	14.2	8.8	16.4	
	Entire car			10.1	7.8	28.4	38.2			1	3.4	2.9	7.7	17.4	21	11.9	25.9	

[1] For data on variety, CO_2, temperature, and length of treatment, see Figs. 8 to 11, inclusive.

A study of the total averages in Table 4 shows that while the percentage of Botrytis infection in the inoculated fruit was small it was three and one-half times greater in the control cars than in the test cars. The Botrytis rot in the uninoculated fruit was two and one-half times greater in the control cars than in the test cars, and the Rhizopus rot 20 per cent greater.

The fruit in the test cars showed a resistance to pressure 29 per cent greater than did that in the control cars and had 26 per cent fewer berries that were too soft for satisfactory marketing.

There was less development of Botrytis rot and less softening of the fruit in the top of the test cars than at the bottom bunker of the control cars. The average temperature at the bottom bunker of the control cars was about 13 degrees lower than the average temperature in the top of the same cars, yet the solid carbon dioxide had a greater inhibiting action upon both the growth of Botrytis rot and the softening of the fruit than this 13-degree lowering of temperature. When it is realized that both the solid carbon dioxide and the carbon dioxide gas had almost entirely disappeared by the time the trip was one-third to one-half completed, the efficacy of the treatment is still more emphasized. The difficulty of controlling Botrytis rot by means of low temperatures has been one of the discouraging features in strawberry shipments; the results of the experiments just described give promise of a practical solution.

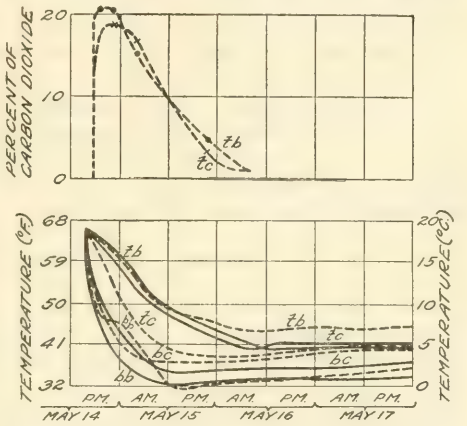

FIGURE 11.—Carbon dioxide curves and temperature curves in an experiment with Klondike strawberries shipped in standard refrigerator cars from Chadbourn, N. C., May 14, 1928. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker; 1,084 pounds of solid CO_2 was used in the test car. It was held on a scaffold in the center of the car about 14 inches above the load. Both cars received 2 per cent of salt at the shipping point and at all reicing stations. The control car required a total of 800 pounds more ice at the reicing stations than the carbon dioxide car. Each car contained 237 crates of berries, making the loads three layers high at the bunkers. The top bunker record for the carbon dioxide car was from the third layer, whereas that from the control was from the second layer

Part of the beneficial effect of solid carbon dioxide on the fruit was due to actual differences in temperature; but the curves in Figures 8 to 11, inclusive, and the reduction in the rots and in the softening of the fruit in the bottom of the test car, as well as in the top, indicate that it must have been largely the result of the inhibiting action of the carbon dioxide gas.

PEACH EXPERIMENTS

Experiments similar to those already described for strawberries were made with peaches. The firmness of the fruit was determined with a pressure tester by the methods described by Magness and Taylor (*22*). The determination of the flavor of the fruit at the close of an experiment was almost as difficult as with strawberries,

and debatable points were settled in a similar manner (p. 8). As with strawberries, the first objectionable result of the carbon dioxide treatments was a slight loss of aroma. With more prolonged and severe treatments there was a still greater loss of normal peach flavor, often accompanied by the development of definitely objectionable flavors.

In the study of the behavior of the peach rots two different methods of inoculation were used. In one, the spores were pushed into the fruit by means of a needle, and two punctures were made in each peach; in the other, 10 punctures were made in each peach with No. 18 wire (paper-clip wire), and the peaches were then inoculated by rolling them gently back and forth in large paper bags together with rotten but firm peaches that were heavily covered with spores. The peaches inoculated by the second method are referred to in the tables as "Monilia dusted."

Inoculations were made with Rhizopus and Monilia. The Rhizopus was obtained from the same source as that reported for strawberries (p. 8) and was therefore known to be *R. nigricans*. The Monilia was obtained from an active peach rot and identified as *Sclerotinia fructicola* (Wint.) Rehm.

PEACHES AT CONSTANT TEMPERATURES

The effect of carbon dioxide upon peaches was tested at various constant temperatures. From 5 to 15 peaches, usually 10, were used under each condition. The peaches were selected individually and with great care in order that those to be compared under different conditions should be as nearly alike as possible in maturity, firmness, size, color, and freedom from injuries. The results of the experiments are shown in Table 5.

Duplicate treatments did not always have the same effect on the flavor, a fact indicating that no sharp line can be drawn as to the tolerance of peaches for carbon dioxide. At 68° and 77° F. a change in flavor sometimes resulted from exposure for 24 hours to atmospheres containing 25 per cent or more of carbon dioxide, and at 50° and 59° from exposure for 48 hours to atmospheres containing 30 per cent of carbon dioxide; yet in many instances much more severe treatments were given without the detection of any change in flavor.

High percentages of carbon dioxide were more injurious than lower ones; yet, with concentrations of 25 per cent or more of the gas, the differences in injury were not particularly pronounced.

As already reported for strawberries (p. 13), there was a marked difference between the carbon dioxide tolerance of peaches at the higher temperatures and that at the lower temperatures. In general, the results in Table 5 indicate that one day's exposure to a particular carbon dioxide treatment at 77° F. is as likely to produce objectionable flavors as two days' exposure to the same treatment at 59°, three days' exposure at 50°, or four days' exposure at 41°. These data are in harmony with the temperature gradients obtained in plant responses in general and suggest a close relationship between the general metabolic activities of the fruit and the degree of susceptibility to injury from atmospheres containing carbon dioxide.

The carbon dioxide treatments had a decided effect upon the firmness of the fruit. At the higher temperatures, atmospheres containing 30 per cent or more of the gas had a checking effect upon the rate of softening approximately equal to a drop of 18° F. in temperature, and at the end of the experiment the fruit had a resistance to pressure about 50 per cent greater than that obtained in the untreated fruit at the same temperatures. In the few tests made with 25 per cent of carbon dioxide, the differences in firmness between the treated and the untreated peaches were practically as great as when the higher percentages of the gas were used.

Carbon dioxide had a very significant inhibiting action upon the development of both Rhizopus and Monilia rots with both methods of inoculation. The extent of the inhibition was determined by holding the fruit at the temperature at which the experiment was made for several days after the test lot was removed from the atmosphere containing carbon dioxide, and then comparing the growth curves of the rots so as to determine the number of hours the rots on the treated fruit lagged behind those on the control fruit. The results, reported in Table 5, are for inoculations made just before the experiment was started and therefore include the incubation period of the rot. However, in a number of duplicate experiments made with rots that had already started, the degree of inhibition was found to be practically the same as in the experiments that included the first stages of rot development.

After removal of the fruit from carbon dioxide the rots usually enlarged at practically the same rate as those on fruit that had not received the gas treatment; but in some instances, especially with the higher concentrations of carbon dioxide, normal activity was not regained immediately upon removal from carbon dioxide, thus indicating that the inhibitory action had extended beyond the period of treatment.

The delay in rot development resulting from exposure to various percentages of carbon dioxide is shown in Table 5. The columns following those that give the hours of delay show the reduction in the efficiency of the fungus as indicated by the ratio of the hours of delay to the hours of treatment.

The reduction in efficiency, or degree of inhibition, was somewhat greater at the lower temperatures than at the higher ones, but the difference was not particularly marked.

The reduction in efficiency varied with the percentage of carbon dioxide used and was approximately in proportion to it. No inhibitory effect was evident after treatment wth 5 per cent of carbon dioxide, but with 10, 25, 30, and 37 per cent the average percentage of reduction in efficiency during the period of treatment was equal to approximately twice the percentage of carbon dioxide used. With 50 per cent of carbon dioxide, almost complete inhibition was obtained during the period of treatment; in some cases a definite inhibitory action extended beyond the time of removal. With 80 per cent of carbon dioxide, the period of delay was nearly always greater than the period of treatment, the fungi showing very definite inhibition after the fruit was removed to normal air.

TABLE 5.—*Effects of different percentages of carbon dioxide on peaches at various constant temperatures*

Variety	Date	CO_2 in atmosphere	Temperature	Length of treatment	Pressure test		Flavor		Delay in rot development due to carbon dioxide after indicated inoculation			Reduction in efficiency of the fungus due to CO_2 as indicated by ratio of hours of delay to hours of treatment after indicated inoculation					
												Monilia needle		Monilia dusted,		Rhizopus needle	
					After CO_2 treatment	Control	After CO_2 treatment	Control	Monilia needle	Monilia dusted	Rhizopus needle	Individual experiments	Average	Individual experiments	Average	Individual experiments	Average
		Per cent	° *F.*	*Hours*	*Lbs.*	*Lbs.*			*Hours*	*Hours*	*Hours*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Belle	July 13, 1927	5	59	72			Good	Good		0				0	0		
Hiley	July 1, 1927	5	50	24			do	do									
Belle	July 5, 1927	5	50	48			do	do									
Do	July 13, 1927	5	50	72			do	do		0				0	0		
Do	Aug. 26, 1927	10	68	72			Bad	do		14				19			
Do	July 18, 1927	10	59	72			Good	do		20				28			
Elberta	July 25, 1927	10	59	72			do	do		37				51	35		
Belle	Aug. 26, 1927	10	59	72			Slightly off	do		19				26			
Do	July 18, 1927	10	50	72			Good	do		35				49	30		
Do	Aug. 26, 1927	10	50	120			Slight CO_2 taste	do		12				10			
Do	do	10	41	120			Good	do		0				0	0		
Do	Sept. 3, 1927	25	77	48			Slight CO_2 taste	do	11			23	33				
Elberta	Sept. 10, 1927	25	77	24			Slightly off	do	10			42					
Belle	Sept. 3, 1927	25	68	48			Slight CO_2 taste	do	23			48	49				
Elberta	Sept. 10, 1927	25	68	24			do	do	12			50					
Belle	July 18, 1927	25	59	72			Good	do	20			28					
Hiley	Aug. 8, 1927	25	59	72			Slightly off	do		38				53	48		
Elberta	Aug. 31, 1927	25	59	72			Good	do		30			40	42			
Belle	Sept. 3, 1927	25	59	72			Slight CO_2 taste	Fair	28			39					
Elberta	Sept. 10, 1927	25	59	48	2.9	1.4	do	Good	26			54					
Hiley	June 29, 1927	25	50	24	2.7	2.4	Good	do									
Elberta	Aug. 31, 1927	25	50	72			do	do		16				22			
Belle	Sept. 3, 1927	25	50	72			do	Fair	55			76	75				
Elberta	Sept. 10, 1927	25	50	72	5.4	3.5	do	Good	53			74					
Do	Aug. 31, 1927	25	41	72			do	do		31				43			
Do	Sept. 7, 1927	25	41	144			Slight CO_2 taste	Flat	140			97	83				
Belle	Sept. 3, 1927	25	41	120			do	Good	82			68					
Elberta	Aug. 23, 1928	30	77	24	12.8	4.7	Good	do	4			17					
Do	Aug. 27, 1928	30	77	24	7.7	2.7	Overripe taste	do	19		10	79	53			42	71
Do	Aug. 30, 1928	30	77	24	13.9	8.5	Good	do	15	16	24	63		67		100	
Do	Aug. 23, 1928	30	68	48	6.4	4.3	do	do	21			44					

Do	Aug. 27, 1928	30	68	24	6.9	4.6	Overripe taste	do	18		26	75	60			108	104
Do	Aug. 30, 1928	30	68	48	7.3	2.7	Slightly insipid	Fair	29	31	48	60		65		100	
Do	Aug. 23, 1928	30	59	96	6.7	3	do	Good	58			60					
Do	Aug. 27, 1928	30	59	48	6.1	5.9	do	do	36			75	62				
Do	Aug. 30, 1928	30	59	72	10.4	3.4	do	do	37	38		51		53			
Do	Aug. 23, 1928	30	50	96	14.7	7.3	Good	do	79			82					
Do	Aug. 27, 1928	30	50	48	10	7.1	Slightly insipid	do	48			100	79				
Do	Aug. 30, 1928	30	50	96	8.4	6.2	Good	do	53	66		55		69			
Do	Aug. 23, 1928	30	41	144	13.4	10	do	do	180			125	97				
Do	Aug. 30, 1928	30	41	120	12.4	11.6	do	do	83	85		69		71			
Carman	Aug. 14, 1928	37	77	24	3.9	1.6	do	do	24			100	100				
Elberta	Aug. 17, 1928	37	77	24	2.8	2.1	Off taste	do	24		24	100				100	
Carman	Aug. 14, 1928	37	68	24	2.9	1.6	Slightly insipid	do	19			79					
Elberta	Aug. 17, 1928	37	68	24	5.7	2.5	do	do	17			71	63				
Do	Sept. 6, 1928	37	68	24	7.3	6.7	Slight CO_2 taste	do	19		22	38				92	
Carman	Aug. 14, 1928	37	59	48	5.8	2	Good	do	39			81	93				
Elberta	Aug. 17, 1928	37	59	25	3.4	4.1	do	do	26			104					
Carman	Aug. 14, 1928	37	50	72	8.7	4.2	do	do	53			74	81				
Elberta	Sept. 6, 1928	37	50	77	9.1	5.7	Slightly insipid	do	67			87					
Carman	Aug. 14, 1928	37	41	96	9	10.5	Good	do									
Elberta	July 25, 1927	46	77	72			Bad	do		40				56			
Belle	Aug. 22, 1927	46	77	48			Strong CO_2 taste	do		9				19	54		
Do	July 31, 1928	46	77	22	5.7	2.5	Slightly insipid	do	14	19	19	64		86		86	
Elberta	July 25, 1927	46	68	72			Bad	do		28				39			
Belle	Aug. 22, 1927	46	68	48			Slightly off	do		20				42			
Do	July 31, 1928	46	68	22	4.5	2.3	Good	do	22	12	24	100		55	42	109	
Elberta	Sept. 11, 1928	46	68	18	9.1	5.9	do	do	11			61	75				95
Do	Sept. 4, 1928	46	68	25	8.1	5.6	Slightly insipid	do	16	8	20	64		32		80	
Belle	July 13, 1927	46	59	72			Good	do		59				82			
Elberta	July 25, 1927	46	59	72			Slight staleness	do		76				100	79		
Belle	Aug. 22, 1927	46	59	48			Slight CO_2 taste	do		17				35			
Do	Aug. 3, 1928	46	59	46	4.2	1.6	Good	do	48	46	80	104		100		174	
Hiley	June 29, 1927	46	50	24	2.4	2.4	do	do									
Do	July 1, 1927	46	50	24			do	do									
Belle	July 5, 1927	46	50	48			do	do									
Do	July 13, 1927	46	50	72			do	do									
Elberta	July 25, 1927	46	50	72			do	do		78				108			
Hiley	Aug. 8, 1927	46	50	72			Slightly insipid	do		64				89			
Belle	Aug. 22, 1927	46	50	48			Slight CO_2 taste	do		6				13	77		
Do	July 31, 1928	46	50	70	4.7	1.6	Good	do	90	90		129		129			
Elberta	Sept. 4, 1928	46	50	48	10.5	9.3	do	do	48	22		100	121	46			
Do	Sept. 11, 1928	46	50	48	9.1	7.1	do	do	64			133					
Hiley	Aug. 8, 1927	46	41	72			do	do									
Belle	Aug. 22, 1927	46	41	120			do	do		12				10	44		
Do	July 31, 1928	46	41	96	3.4	3	Slightly insipid	do	82	75		85		78			
Elberta	Sept. 4, 1928	75	68	25	8	5.6	Slightly off	do	24	20	32	96		80		128	146
Do	Sept. 6, 1928	75	68	24	7.8	6.7	Slight CO_2 taste	do	22		39	92	107			163	
Do	Sept. 11, 1928	75	68	18	11.5	5.9	Good	do	24			133					
Do	Sept. 4, 1928	75	50	48	9.7	9.3	do	do	54	75		113		156			
Do	Sept. 6, 1928	75	50	77	9.2	5.7	Slightly off	do	90			117	118				
Do	Sept. 11, 1928	75	50	48	10.1	7.1	Good	do	60			125					

In most of the experiments, tests were carried out at several different temperatures at the same time with peaches from the same lot. This gave an opportunity to compare the development of the rots on the treated fruit at the higher temperatures with that on the untreated fruit at the lower temperatures, thus converting the inhibitory action of the carbon dioxide into approximate temperature equivalents. The temperature curves of Figures 12 and 13, showing the working efficiency of Monilia and Rhizopus at different temperatures, were also of aid in this conversion of values (*6*). While the results have been somewhat variable, it can be said in general that holding peaches at 77° F. in 10, 25, 30, 37, and 46 per cent of carbon dioxide had effects upon the rots roughly equivalent to holding them during the period of treatment at temperatures 12°, 22°, 27°, 33° and 40° lower, respectively. Similar gas treatments at 68° had inhibitory effects upon the rots approximately equivalent to temperature reductions of 6°, 14°, 20°, 26° and 32°, respectively. Similar treatments at 59° caused corresponding inhibitions approximately equivalent to reductions of 6°, 12°, 16°, 22°, and 25°, respectively. Putting the results in more general terms, atmospheres carrying 30 to 37 per cent of carbon dioxide had a checking effect upon the rots theoretically equivalent to the immediate cooling of the fruit from common summer loading temperatures to temperatures that are usually obtained only after one or often two days of refrigeration.

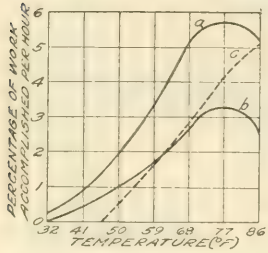

FIGURE 12. — Temperature curves for the incubation period of peach rots, showing the relative efficiency of the fungi at different temperatures: *a*, Monilia needle inoculations; *b*, Monilia dusted inoculations; *c*, Rhizopus needle inoculations. (After Brooks and Cooley, *6*)

PEACHES IN PONY REFRIGERATORS

The pony-refrigerator experiments with peaches were carried out as described under Methods and Apparatus (p. 7). The results are shown in Table 6 and in Figures 14 to 21, inclusive.

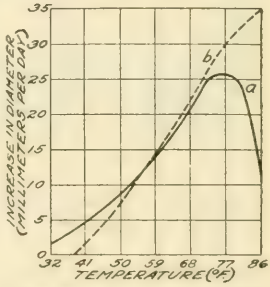

FIGURE 13. — Temperature curves based on the hourly increase in diameter of peach rots: *a*, Monilia; *b*, Rhizopus. (After Brooks and Cooley, *6*)

The use of solid carbon dioxide as a supplementary refrigerant usually resulted in lower temperatures and more rapid cooling, but possibly its most striking refrigerating effect was in delaying the melting of the ice. A similar condition has already been pointed out under the discussion for strawberries. (P. 15.)

Judging by most of the results in the constant-temperature experiments with peaches (Table 5), it would hardly be expected that the gas treatments shown in Figures 14 to 21, inclusive, would affect the flavor of the fruit; but in several instances the peaches were rendered insipid or developed objectionable flavors. The correlation between treatment and effect was not particularly close. In

general it may be said that under the conditions of the experiments peaches that were subjected to 25 per cent or more of carbon dioxide for as long a period as 24 hours were usually found at the close of the experiment either to be lacking in flavor or to have a distinctly objectionable taste. In experiments where high percentages of carbon dioxide were maintained for somewhat shorter periods the flavor of the peaches remained unaffected.

The effect of the gas treatments upon the firmness of the peaches was usually pronounced. Excluding the tests in which the flavor of the peaches was affected, at the end of the experiments the average resistance to pressure was decidedly higher in the refrigerators in which solid carbon dioxide was used than in the controls. The temperature differences between the various refrigerators were not sufficient to account for much of this difference; it must therefore be attributed largely to the effect of the gas.

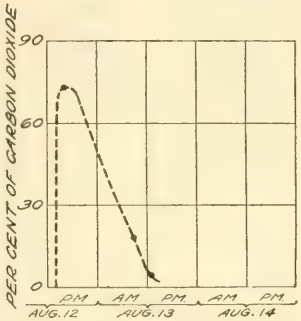

FIGURE 14. — Carbon dioxide curve in an experiment with Hiley peaches in pony refrigerators, August 12 to 14, 1927. The refrigerators were of the 32-quart size. The control refrigerator received 60 pounds of ice, the test refrigerator 40 pounds of ice and 20 pounds of solid CO_2. The curve above shows the approximate percentage of carbon dioxide in the test refrigerator. The temperature in the test refrigerator was 33° F. at midnight August 12 and 42° at 9 p. m. August 13. The minimum temperature for the control refrigerator was 47°

The carbon dioxide gas also had a very decided inhibiting effect upon both Rhizopus and Monilia rots. (Table 6.) In most instances the peaches were held at a temperature of 59° F. for several days after removal from the pony refrigerators, and daily measurements of the rots were taken during this period. On the basis of growth at this temperature, the rots on the fruit from the various refrigerators containing solid carbon dioxide were one to three days behind those on the fruit from the control refrigerators. In some instances, especially with Rhizopus and with Monilia-dust inoculations, the rots were greatly decreased in number as well as in size. Rose and Butler (*29*) have shown that when fungus cultures are moved from lower to higher temperatures there is a lag in growth that is correlated with, and apparently due to, the temperatures at which they had previously been held. In the present experiments, however, the control lots of fruit were subjected to practically the same changes in temperature as were the test lots; therefore the effect of the previous temperature is not a factor in later comparisons.

TABLE 6.—*Condition of peaches held in pony refrigerators with solid carbon dioxide as a supplementary refrigerant* [1]

Figure reference [1]	Ice		Solid CO_2	Pressure test upon removal	Flavor upon removal	Rots from indicated inoculations							
						Rhizopus needle		Monilia dusted		Monilia needle			
										Average diameter of rots after removal [2]		Reduction in efficiency of fungus due to CO_2 gas, expressed as—	
	At beginning	At end				Average infection after removal [2]	Average diameter of rots after removal [2]	Infection upon removal	Infection after removal [2]	First record	Later record	Inhibition period from beginning of experiment	Percentage for total period in refrigerator
	Pounds	*Pounds*	*Pounds*	*Ounces*		*Per cent*	*Mm*	*Per cent*	*Per cent*	*Mm*	*Mm*	*Hours*	*Per cent*
Fig. 14	60	0	0	10	Good				(1) 86				
	40	6	20	12.6	do				(1) 22				
Fig. 15:													
a	60		0	1.2	do			33					
b	40		20	2.9	do			5					
Fig. 16:													
a	60	9	0	6.2	do					(0) 3	(2) 16.7		
b	30	9	26	8.1	do					(0) 0	(2) .2	89	100
Fig. 17:													
a	60+58		0	5.5	Poor	(2) 100	(2) 21.5			(0) 16.5	(2) 26.7		
b	35		25+15	8	Slightly off	(2) 0	(2) 0			(0) 0	(2) 0	78	100
Fig. 18:													
a	135	4	0	5.1	Good					(1) 9	(2) 21.5		
b	120	12	15	7.5	do					(1) 0	(2) 5.5	70	100
c	110	8	25	8.1	do					(1) 0	(2) 0	96	100
d	100	18	35	9.1	do					(1) 0	(2) 9.1	61	94
Fig. 19:													
a	141	5	0	9.4	do			5	(1) 34	(0) 7.1	(1) 21.3		
b	126	15	15	9.7	do			0	(1) 0	(0) .3	(1) 7.7	39	62
c	111	20	30	11.4	Slightly off [3]			0	(1) 0	(0) 0	(1) 8.2	42	65
d	87	25	50	10	Distinctly off [3]			0	(1) 0	(0) 0	(1) 3.7	68	96

Fig. 20:													
a	140	10	0	12.6	Fair			0	(2) 69	(0) 6.3	(1) 16.5		
b	90	33	50	13	do			0	(2) 4	(0) 0	(1) 0	69	100
c	90	34	50	13.5	do			0	(2) 1	(0) 0	(1) 0	72	100
d	90	35	50	14.1	do			0	(2) 4	(0) 0	(1) 0	78	100
Fig. 21:													
a	140	0	0	4.6	Fair to good	(3) 95	(3) 52.6	30	(1) 46	(0) 16.5	(1) 24		
b	120	6	20	6.5	Slightly insipid	(3) 50	(3) 6.8	0	(1) 0	(0) 0	(1) 5	65	93
c	100	19	40	7.9	Insipid	(3) 75	(3) 4.5	0	(1) 3	(0) 0	(1) 0	84	100
d	100	17	40	5.8	Slightly insipid	(3) 60	(3) 6	0	(1) 14	(0) 0	(1) 0	79	100

[1] For data on variety, CO_2, temperature, and length of treatment see Figs. 14 to 21, inclusive.
[2] Numbers in parentheses indicate number of days fruit was held at 59° F. after removal.
[3] The flavor became normal after the fruit had been held 2 days at 59° F. after removal.

By the use of the equivalent temperature values shown in Figures 12 and 13, it is possible to separate the effect of carbon dioxide gas on the rots from the effect of any differences in temperature. If the temperature values of Figures 14 to 21 are converted into work units according to the Monilia needle-inoculation values of Figures 12 and 13, it is possible to compare the relative efficiency of the fungus under the different treatments, with the temperature factor eliminated. The results of such a comparison are shown in the last two columns of Table 6. In 9 out of the 14 cases analyzed, the fungus was checked by the carbon dioxide treatment to a degree equivalent to total inhibition during the entire period in the refrigerator, and in

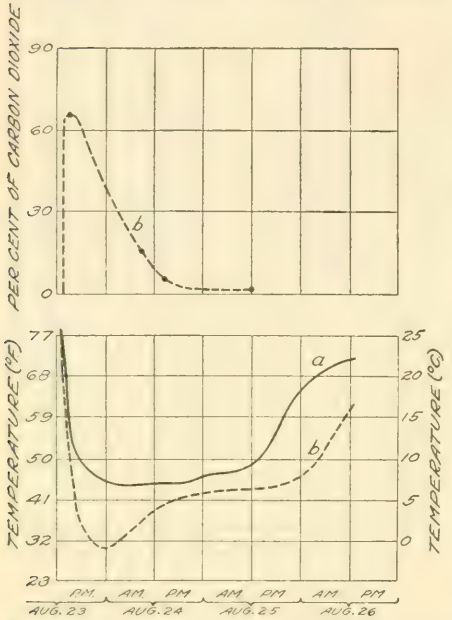

FIGURE 15.—Carbon dioxide curve and temperature curves in an experiment with Belle peaches in 32-quart pony refrigerators, August 23 to 26, 1927: *a*, Control refrigerator with 60 pounds of ice; *b*, refrigerator with 40 pounds of ice and 20 pounds of solid CO_2. The thermographs were covered with fruit but near the top of the refrigerator

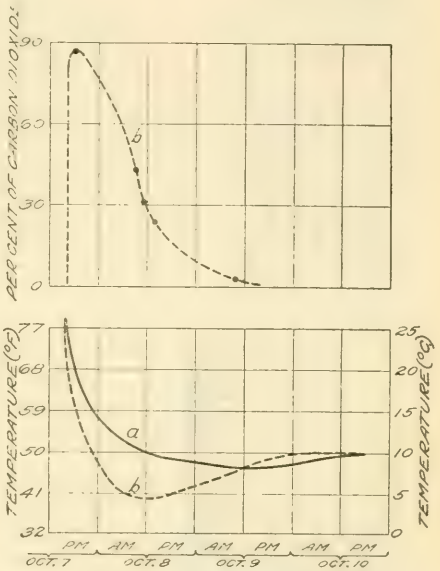

FIGURE 16.—Carbon dioxide curve and temperature curves in an experiment with Krummel peaches in 32-quart pony refrigerators, October 7 to 10, 1927: *a*, Control refrigerator with 60 pounds of ice; *b*, refrigerator with 30 pounds of ice and 26 pounds of solid CO_2

several instances complete inhibition can be considered to have extended over into the period of storage at 59° F. When it is noted from the curves in Figures 14 to 21 that the carbon dioxide had usually escaped from the refrigerators several hours before the fruit was removed, the extent of the inhibition is still more emphasized.

The number of hours of inhibition or the percentage of inhibition reported in any particular instance must, of course, be regarded as approximate; but the results as a whole give great emphasis to the possible value of carbon dioxide gas as a deterrent to fungal invasion.

Mathematical computation of the inhibition in Rhizopus needle inoculations and in the dusting inoculations with Monilia has not been attempted; but the data given in Table 6, and other records not

reported, are sufficient to show that the inhibition in both of these cases was as great as that with the Monilia needle inoculations.

PEACHES IN REFRIGERATOR CARS

Solid carbon dioxide was used also in car-lot shipments of peaches. The method of handling has been described under Methods and Apparatus (p. 7), and the methods used in the inoculation of the fruit are described on page 22.

All the inoculations were made at one time and the inoculated fruit packed at once beside the recording thermometers. It often happened

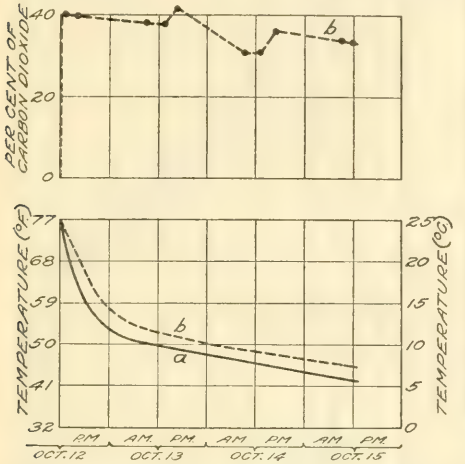

FIGURE 17.—Carbon dioxide curve and temperature curves in an experiment with Elberta peaches in 32-quart pony refrigerators, October 12 to 15, 1927: *a*, Control refrigerator with 60 pounds of ice at the beginning of the experiment, 31 pounds added October 13 at 4 p. m., and 27 pounds added October 14 at 1 p. m.; *b*, refrigerator with 35 pounds of ice and 25 pounds of solid CO_2 at the beginning of the experiment and 15 pounds solid CO_2 added October 14 at 1 p. m. One layer of insulating felt was used between the fruit and the ice pan in *a*, and two layers of felt in *b*

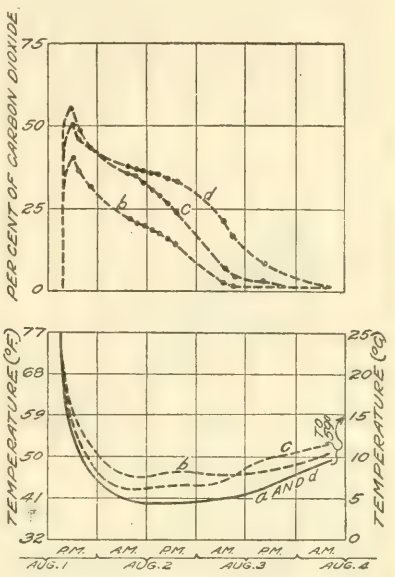

FIGURE 18.—Carbon dioxide curves and temperature curves in an experiment with Belle and Elberta peaches in 80-quart pony refrigerators, August 1 to 4, 1928. *a*, Control refrigerator with 135 pounds of ice; *b*, refrigerator with 120 pounds of ice and 15 pounds of solid CO_2; *c*, refrigerator with 110 pounds of ice and 25 pounds of solid CO_2; *d*, refrigerator with 100 pounds of ice and 35 pounds of solid CO_2. The temperatures reported are the average of records from the top and bottom layers of baskets. On August 4 record fruit was transferred to 59° F. storage chamber

that one of the cars was loaded earlier than the others; in such cases an effort was made to maintain similar temperature conditions by placing all the test fruit in the car that was being loaded. This sometimes resulted in a drop in temperature during loading followed by a rise in temperature when the test crates were finally placed in position together with warmer fruit. The temperature and carbon-dioxide records are given in Figures 22 to 26, inclusive, and the icing records and the time and place of shipment are reported in the legends to these figures.

As shown in Figures 22, 23, 24, and 26, the solid carbon dioxide resulted in a more rapid cooling of the fruit in the top of the load, but Figure 25 shows that the cooling in the top of the carbon dioxide

car was slightly behind that in the control car and decidedly behind that in the blower car.

In the experiment of Figure 22 the carbon dioxide content of the air in the refrigerator car remained about 18 to 20 per cent for the first 5 hours after the car was closed and probably dropped rapidly after that. In the experiment of Figure 26 the carbon dioxide was above 20 per cent for 10 hours and above 10 per cent for 18 hours, and in the experiments shown in Figures 23, 24, and 25 it was above 20 per cent for about 14 hours and above 10 per cent for 23 hours or longer. The percentage of gas in some shipments (figs. 23 and 24) was but little greater than in others (figs. 25 and 26), yet far more solid carbon dioxide was used. This difference was apparently due to the fact that the cars of the later shipments were new, whereas those of the earlier shipments were not.

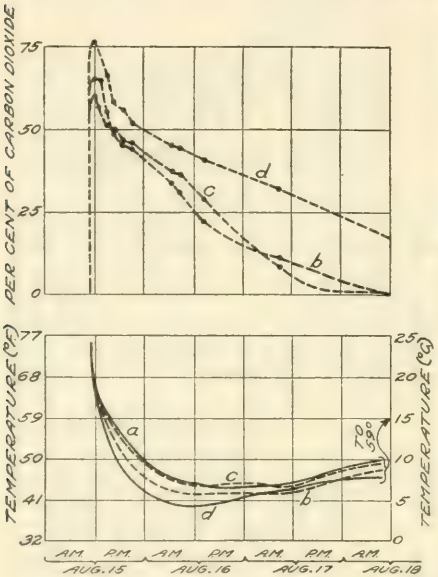

FIGURE 19.—Carbon dioxide curves and temperature curves in an experiment with Belle peaches in 80-quart pony refrigerators, August 15 to 18, 1928: *a*, Control refrigerator with 141 pounds of ice; *b*, refrigerator with 126 pounds of ice and 15 pounds of solid CO_2; *c*, refrigerator with 111 pounds of ice and 30 pounds of solid CO_2; *d*, refrigerator with 87 pounds of ice and 50 pounds of solid CO_2. The temperatures reported are the average of records from the top and bottom layers of baskets

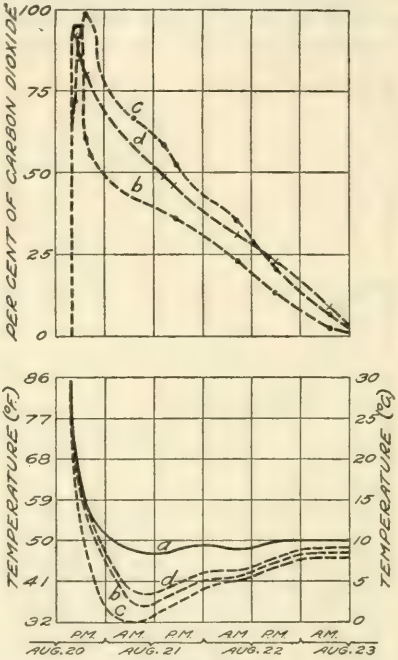

FIGURE 20.—Carbon dioxide curves and temperature curves in an experiment with Belle peaches in 80-quart pony refrigerators, August 20 to 23, 1928: *a*, Control refrigerator with 140 pounds of ice; *b*, *c*, and *d*, three different refrigerators, each with 90 pounds of ice and 50 pounds of solid CO_2; *b* differed from the others in having two ⅜-inch holes in the bottom of the fruit chamber. The temperatures reported are the average of records from the top and bottom layers of baskets

In all cases critical tests were made as to the flavor of the fruit at destination, but there was no indication of any unfavorable effect resulting from exposure to the carbon dioxide gas. The peaches from the test cars tasted somewhat greener in some instances than did those in the control cars, and the pressure tests showed that they were actually less mature; but the differences in flavor were not unlike the differences found between the fruit in the top and the

bottom of the same car. In one shipment (fig. 24) the fruit was held in cold storage for two weeks after unloading; at the end of that time the flavor of the peaches from the test car was fully as good as that of the peaches from the control car.

Sample lots of fruit from the other shipments were forwarded to Washington, D. C., for further tests on flavor. In no instance was any distinctly objectionable flavor detected, but in two shipments (figs. 25 and 26) the fully ripened peaches of the test cars had a slightly different flavor from those of the control car. The variation within the particular lots was much greater than the difference between the lots, but on the whole the fruit from the test car seemed to show a slight reduction in aroma, acidity, and juiciness, and a slight increase in sweetness. In Elberta peaches the usual bitter flavor was lacking in the treated fruit while still present in the untreated. Of a group of 8 persons who critically tested the fruit from the first of these shipments (Belle), 3 could detect no difference in flavor, 4 preferred the fruit that had been exposed to carbon dioxide, and 1 preferred the fruit from the control car; and of a group of 16 who tested the fruit from the second shipment (Elberta), 5 could find no difference in flavor, 5 preferred the fruit from the test car, and 6 preferred the fruit from the control car.

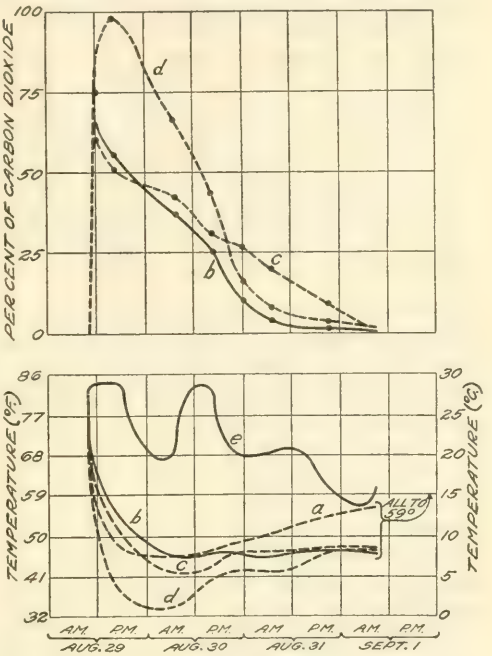

FIGURE 21.—Carbon dioxide curves and temperature curves in an experiment with Elberta peaches in 80-quart pony refrigerators, August 29 to September 1, 1928: *a*, Control refrigerator with 140 pounds of ice; *b*, refrigerator with 120 pounds of ice and 20 pounds of solid CO_2; *c*, refrigerator with 100 pounds of ice and 40 pounds of solid CO_2 (large pieces); *d*, refrigerator with 100 pounds of ice and 40 pounds of solid CO_2 (small pieces); *e*, outside temperature. On September 1 record fruit was transferred to 59° F. storage chamber

As in previous experiments, the carbon dioxide had a very decided effect upon the firmness of the fruit. The average resistance to the pressure tester for the peaches in the top of the five test cars was practically the same as that for the peaches in the bottom of the five control cars and differed but little from that before shipment, whereas the average pressure test for the peaches in the top of the five control cars was 36 per cent lower.

The carbon dioxide did not show quite so great inhibiting action on the growth of the fungi as it did on the softening of the fruit, yet the contrasts were very significant. The average development of the rot organisms in the top of the test car was greater than that in the

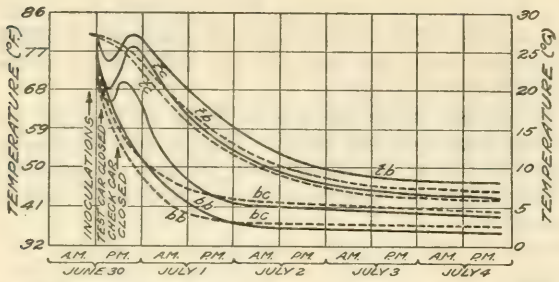

FIGURE 22.—Temperature curves in an experiment with Belle peaches shipped in refrigerator cars from Fort Valley, Ga., June 30, 1927. The broken lines give the records for the test car, the solid lines the records for the control car; *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to standard icing, 430 pounds of solid CO_2 held in crates scattered over the top of the load and somewhat insulated from it. At 2 p. m. the atmosphere in the test car contained 12.5 per cent of CO_2; at 2.30 p. m., 18 per cent; and from 3.30 till 7 p. m., 20 to 21 per cent. The top center and bottom bunker atmospheres showed practically no difference. There were 476 crates of peaches in each car

bottom of the control car, but less than the average development in the control car.

The average difference in temperature between the top and bottom of the control cars was 13.1 degrees Fahrenheit, and the average difference in temperature between the top of the control cars and the average temperature for these cars was 6.6 degrees. Expressed in temperature values, the use of solid carbon dioxide had an effect upon the softening of the fruit equal to a 13.1-degree reduction in temperature during the entire trip and an effect upon the rots greater than that of a 6.6-degree reduction in temperature during the entire trip. If it is assumed that this inhibiting effect upon the rots was confined to the first 36 hours after loading, as it probably was to a large extent, it may be said that during this period the solid carbon dioxide had an inhibiting effect upon the rots approximately equal to that of an 18-degree drop in temperature.

If the behavior of the Monilia rots is studied on the basis of the values in Figures 12 and 13, the differences in growth may be interpreted in terms of the degree of inhibition in the test car as compared with that in the control car. It is found, for example, that in the shipment shown in Table 7 under Figure 23 the rots in the

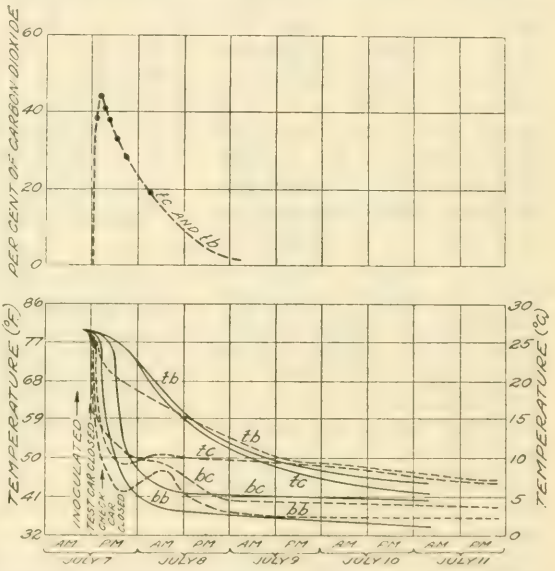

FIGURE 23.—Carbon dioxide curve and temperature curves in an experiment with Hiley peaches shipped in refrigerator cars from Fort Valley, Ga., July 7, 1928. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to standard icing, 884 lines the records for the control car: *tc*, Top center; of the car about 16 inches above the load. The test car received 100 pounds more ice at the reicing stations than did the control car but was unloaded 18 hours later than the control car

top of the test car showed a reduction in efficiency equal to 19 per cent for the whole shipping period, and those in the bottom of the car a similar reduction of 8 per cent; in the shipment described in Figure 24 the rots in the top of the test car showed a reduction of 48 per cent, and those in the bottom a reduction of 44 per cent. The data in Table 7 show that the inhibition of the Rhizopus rots was equally great.

In some instances the better condition of the fruit in the test car, as to firmness and decay, may have been partly due to differences in temperature; but a study of the curves in Figures 22 to 26, inclusive, leads to the conclusion that it must have been largely due to the effect of the carbon dioxide gas.

From the economic standpoint it should be noted that, as shown in Table 7 under Figure 23, the fruit in the test car was in distinctly better condition on arrival than that in the control car, both as to firmness and rot development, in spite of the fact that the control car was unloaded 18 hours earlier. In two cars unloaded at practically the same time (fig. 24), the condition of the fruit in the control car was such as to make it necessary to place it on the market at once, whereas the fruit in the test car was placed in storage to be held for later sales. The inoculated fruit from both cars was transferred to cold storage, however, and it was found that the development of rots on the peaches from the test car after two weeks in storage only slightly exceeded that of the rots on the peaches from the control car at the time of unloading.

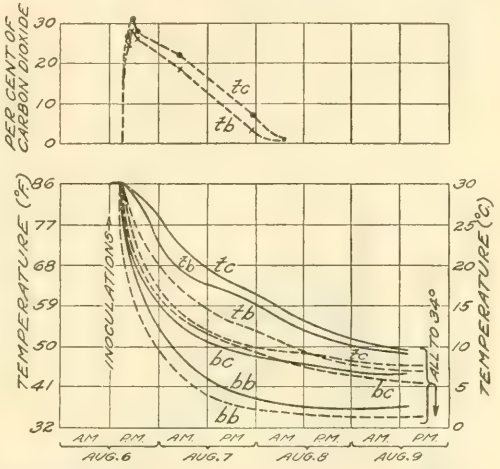

FIGURE 24.—Carbon dioxide curves and temperature curves in an experiment with Elberta peaches shipped in refrigerator cars from Hamlet, N. C., August 6, 1928. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to standard icing 1,000 pounds of solid CO_2 held on a scaffold in the center about 16 inches above the load. The test car also received 2 per cent of salt in the bunkers at the shipping point. The control car required 2,100 pounds more ice at the reicing stations than the test car. On August 9 record fruit was transferred to 34° F. storage

One shipment (fig. 25) included a car in which a Galloway precooling apparatus[4] was used in comparison with the carbon dioxide car and with the control car. The results, as given in Table 7, show practically the same resistance to pressure in the fruit of the blower car (with precooling apparatus) as in that of the carbon dioxide car. The development of Monilia and Rhizopus rots, however, was very much greater in the blower car than in the carbon dioxide car and not greatly different from that in the control car.

[4] GALLOWAY, A. G. A PORTABLE PRECOOLING APPARATUS. U. S. Department of Agriculture, Bur. Plant Indus., July 15, 1929. [Mimeographed.]

Another shipment (fig. 26) included a salted car in addition to the control car and the carbon dioxide car, the latter also salted. The average results on firmness and decay in the salted car fell about halfway between those in the control car and those of the carbon dioxide car, but in the top of the load the results on both firmness and decay were practically the same as those in the control.

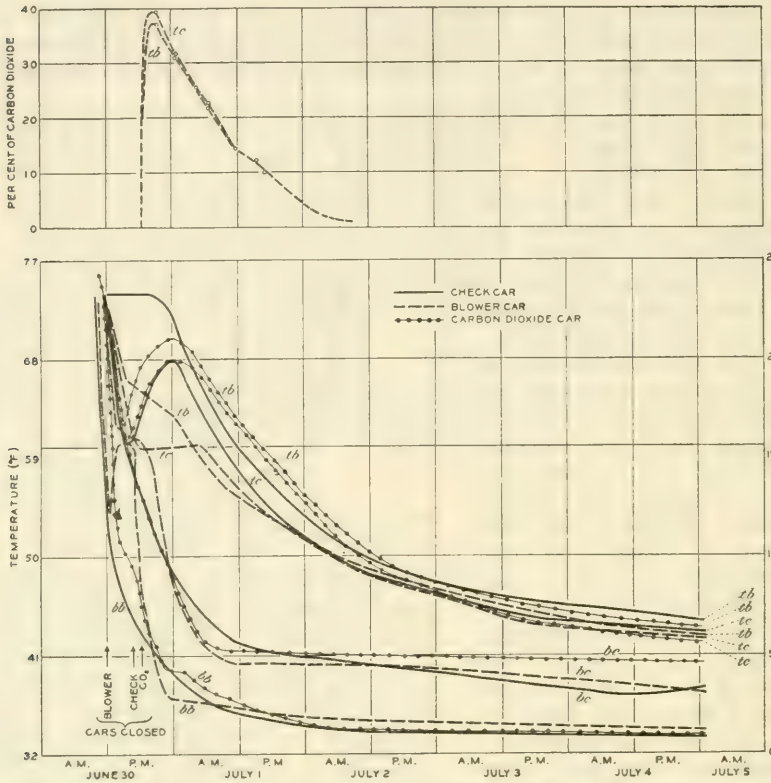

FIGURE 25.—Carbon dioxide curves and temperature curves in an experiment with Hiley peaches shipped in refrigerator cars from Thomason, Ga., June 30, 1930: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The carbon dioxide car received 450 pounds of solid CO_2 placed in crates on top of the load. The carbon dioxide car had 400 pounds of salt added at the shipping point and the blower car 300 pounds. The solid carbon dioxide car required 200 pounds and the control car 1,070 pounds more ice than did the blower car

DEWBERRY EXPERIMENTS

The dewberry is even more perishable than the strawberry but may be exposed to carbon dioxide gas with far less danger of injury than either the peach or the strawberry.

In the experiments with dewberries no inoculations were made, and no satisfactory method was devised for measuring the firmness of the fruit. Before the experiments were started, however, sample lots of fruit were graded, and the berries were classified as firm, soft, or rotten. At the end of the experiments similar lots were graded according to the same standards to determine the increase in rot and the decrease in the number of firm berries.

DEWBERRIES IN PONY REFRIGERATORS

The pony-refrigerator experiments were carried out as described for strawberries (p. 7). The results are shown in Table 8. In the experiments of Figures 3, 4, 7, and 20, only a few baskets of dewberries were used in each refrigerator, the main experiment being upon another fruit. In the experiments shown in Figures 27 and 28 the refrigerators were filled with dewberries, with the exception of small lots of other fruits, as will be pointed out later.

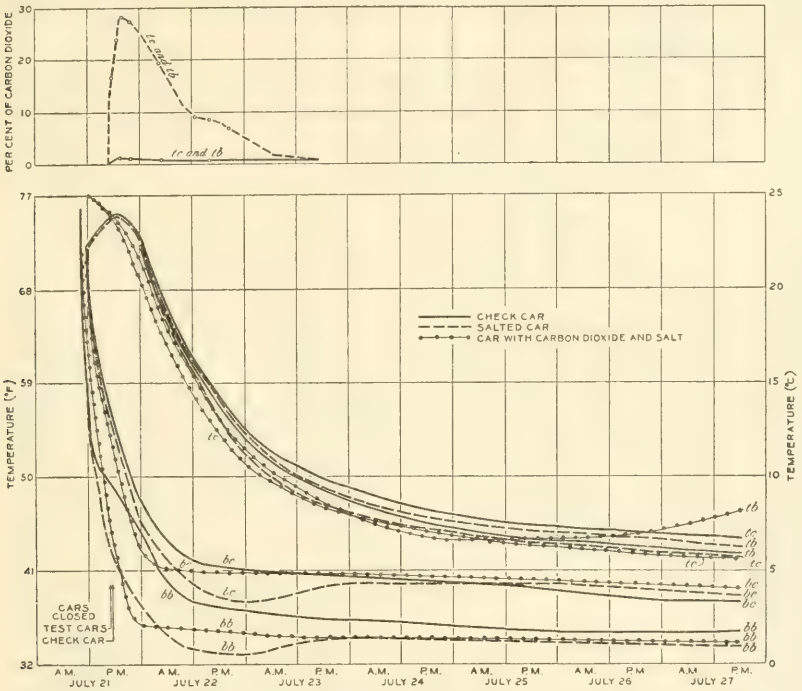

FIGURE 26.—Carbon dioxide curves and temperature curves in an experiment with Elberta peaches shipped in refrigerator cars from Thomaston, Ga., July 21, 1930: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The carbon dioxide car received 466 pounds of solid CO_2 placed in crates on top of the load and an additional 113 pounds placed in the bunkers. The carbon dioxide car had 400 pounds of salt added at the shipping point and the salted car 300 pounds at shipping point and 189 pounds en route. The salted car required 4,284 pounds and the control car 5,670 pounds more ice than did the solid carbon dioxide car

The flavor of the dewberries remained unimpaired under all the conditions of the various experiments, despite the fact that the carbon dioxide treatment was sometimes even more severe than that which had usually spoiled the flavor of peaches and strawberries. In the experiment reported in Figure 4 a small lot of dewberries was included with a strawberry test, and in the experiments reported in Figures 27 and 28 small lots of strawberries were included with the dewberry tests. In all three experiments the flavor of the dewberries was unaffected by the carbon dioxide treatment, whereas the flavor of the strawberries was rendered either insipid or distinctly bad.

TABLE 7.—*Condition of peaches and peach-rot organisms after shipment in standard refrigerator cars with different methods of cooling*

Figure reference [1]	Location in car	Flavor of peaches in—				Pressure test of peaches in—				Rots from Monilia needle inoculations					
										Peaches infected in—		Diameter of rots on peaches in—			
		Carbon dioxide car	Control car	Blower car	Salted car	Carbon dioxide car	Control car	Blower car	Salted car	Carbon dioxide car	Control car	Carbon dioxide car	Control car	Blower car	Salted car
						Ounces	*Ounces*	*Ounces*	*Ounces*	*Per cent*	*Per cent*	*Mm*	*Mm*	*Mm*	*Mm*
	Top center	Good	Good			15.2	10.2								
	Top bunker	do	do			13.4	3.2								
	Average top of car					14.3	6.7								
Fig. 22	Bottom center	Good	Good			15.2	13.5								
	Bottom bunker	do	do			17.1	14.5								
	Average bottom of car					16.2	14								
	Average for car					15.2	10.4								
	Top center	Good	Good			13.1	7.2			100	100	15.8	28.9		
	Top bunker	do	do			11.8	9.3			100	100	28.7	31.4		
	Average top of car					12.5	8.3			100	100	22.3	30.4		
Fig. 23 [2]	Bottom center	Good	Good			12.6	13.2			95	100	7.1	9.9		
	Bottom bunker	do	do			12.8	12.5			90	100	4.6	4.2		
	Average bottom of car					12.7	12.9			92.5	100	5.9	7.1		
	Average for car					12.6	10.6			96.3	100	14.1	18.7		
	Top center	Good	Good			13.4	6.2			55	100	4.7	33.5		
	Top bunker	do	do			12.8	8.4			95.1	100	6.7	26.2		
	Average top of car					13.1	7.3			75.1	100	5.7	29.9		
Fig. 24	Bottom center	Good	Good			14.4	12.1			15	90	3	7.7		
	Bottom bunker	do	do			13.8	14.2			5	53.6	3	2.8		
	Average bottom of car					14.1	13.2			10	71.8	3	5.3		
	Average for car					13.6	10.2			42.5	85.9	4.4	17.6		
	Top center	Good	Good	Good		14.6	13.6	14.3				38.5	45.1	41.2	
	Top bunker	do	do	do		14.4	12.4	14.7				32.4	45.2	46.3	
	Average top of car					14.5	13	14.5				35.5	45.2	43.8	
Fig. 25	Bottom center	Good	Good	Good		14	13.8	13.7				17.2	20.8	23.2	
	Bottom bunker	do	do	do		14	14.7	14.5				9.3	17.1	19.5	
	Average bottom of car					14	14.3	14.1				13.3	19	21.4	
	Average for car					14.3	13.6	14.3				24.4	32.1	32.6	
	Top center	Good	Good		Good	11.2	6.1		5.6			44	54.5		52
	Top bunker	do	do		do	10.2	5.9		7.3			40.8	55.4		52.7
	Average top of car					10.7	6		6.5			42.4	55		52.4
Fig. 26	Bottom center	Good	Good		Good	14.7	[3] 7.8		[3] 12.7			14.4	[3] 22.1+6		[3] 13.1+3.2
	Bottom bunker	do	do		do	13.5	[3] 14		[3] 13.5			4	[3] 6.0+4		[3] 2.7+1.8
	Average bottom of car					14.1	10.9		13.1			9.2	14.1		7.9
	Average for car					12.4	8.5		9.8			25.8	34.6		30.2
	Top of car					13	8.3			87.6	100	26.5	40.1		
Average	Bottom of car					14.2	13.1			51.3	85.9	7.9	11.4		
	Entire car					13.6	10.7			69.4	93	17.2	25.8		

Figure reference [1]	Rots from Monilia dusted inoculations				Rots from Rhizopus needle inoculations						Increase in diameter of colonies of rot organisms in Petri dish							
	Peaches infected in—		Diameter of rots on peaches in—		Peaches infected in—		Diameter of rots on peaches in—				Monilia in—				Rhizopus in—			
	Carbon dioxide car	Control car	Carbon dioxide car	Control car	Carbon dioxide car	Control car	Carbon dioxide car	Control car	Blower car	Salted car	Carbon dioxide car	Control car	Blower car	Salted car	Carbon dioxide car	Control car	Blower car	Salted car
	Per cent	*Per cent*	*Mm*	*Mm*	*Per cent*	*Per cent*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*
Fig. 22	36	30.8	6.2	8.5														
	51.4	96.7	8.3	14.1														
	43.7	63.8	7.3	11.3														
Fig. 23 [2]	34.3	99.5	6.4	9.8	0	86	0	5										
	90.5	94.5	7	10	0	0	0	0										
	62.4	97	6.7	9.9	0	43	0	2.5										
	15	20	2.3	2.8	0	0	0	0										
	23.6	.5	2.1	2	0	0	0	0										
	19.3	10.3	2.2	2.4	0	0	0	0										
	40.9	53.7	4.4	6.2	0	21.5	0	1.3										
Fig. 24	5	87	3.4	10.9	0	45.1	0	5.5										
	5	60	4	10.3	0	39.9	0	8.3										
	5	73.5	3.7	10.6	0	42.5	0	6.9										
	3	8	3	10	0	0	0	0										
	3	2	3	2	0	0	0	0										
	3	5	3	6	0	0	0	0										
	4	39.3	3.4	8.3	0	21.3	0	3.5										
Fig. 25							1.5	6.7	13.4		26	36	34.5					
							13.2	18.6	17.4		27	38.8	34					
							7.4	12.7	15.4		26.5	37.4	34.3					
							0	0	0		7.9	13.2	14.5		17.5	28	36	
							.5	.8	0		1.1	3	5.2		5	5.5	16.5	
							.3	.4	0		4.5	8.1	9.9		11.3	16.8	26.3	
							3.8	6.5	7.7		15.5	22.8	22.1					
Fig. 26							2	3.2		2	20.7	36		33.5				
							4.7	9.4		4.7	24.5	35.5		37				
							3.4	6.3		3.4	22.6	35.8		35.3				
							0	0		0	0	[3] 12		[3] 6	4	11		6
							0	0		0	0	[3] 4		[3] 3	0	0		0
							0	0		0	0	8		4.8	2	5.5		3
							1.7	3.2		1.7	11.3	21.9		20.1				
Average	33.7	85.3	5.2	10.3			2.7	7.1			24.6	36.6						
	11.2	7.7	2.6	4.2			.1	.1			2.3	8.1			6.7	11.2		
	22.5	46.5	3.9	7.3			1.4	3.6			13.4	22.4						

[1] For data on variety, CO_2, temperature, and treatment, see Figs. 22 to 26, inclusive.

[2] The test car was unloaded 18 hours after the control car, but no adjustment has been made in the data.

[3] The bottom of the salted car was unloaded 26 hours and the bottom of the control car 48 hours after the carbon dioxide car. The sum of the two numbers given under Monilia represents the total growth at the time of unloading, the first of the numbers giving the estimated growth at the time the carbon dioxide car was unloaded, and the second number the estimated growth during the further delay. The change in the Rhizopus rots and in the softening of the fruit during the delay was probably extremely small.

TABLE 8.—*Condition of dewberries after being held in pony refrigerators with solid carbon dioxide as a supplementary refrigerant*

Figure reference [1]	Ice		Solid CO_2	Flavor	Decrease in firm berries	Increase in rotten berries
	At beginning	At end				
	Pounds	*Pounds*	*Pounds*		*Per cent*	*Per cent*
Fig. 3	135	16	0	Good		
	120	32	15	do		
	110	40	25	do		
	100	47	35	do		
Fig. 4	144	36	0	do	64.1	32.5
	119	42	15	do	17.3	4.3
	119	23	20	do	18.4	8.9
	110	44	30	do	25.7	9.3
Fig. 7	163	22	0	do		
	147	23	7	do		
	94	12	12	do		
Fig. 20	140	10	0	do		
	90	33	50	do		
	90	34	50	do		
	90	35	50	do		
Fig. 27	163	18	0	do	53.9	46.1
	133	33	28	do	9.1	13.8
	97	45	28	do	17.0	18.5
Fig. 28	170	13	0	do	11.5	9.1
	133	30	35	do	6.8	2.8
	101	46	36	do	1.4	1.3

[1] For data on temperature, CO_2 and length of treatment, see Figs. 3, 4, 7, 20, 27, and 28.

The carbon dioxide always had an inhibiting action on the rots of the dewberries and always helped to maintain the firmness of the fruit. In the three experiments in which complete records were kept, both the average percentage of rot and the average decrease in firm berries in the treated lots were less than a third of the averages in the fruit from the control refrigerators. (Table 8.) In some cases these differences may have been partly due to the differences in temperature, but a study of the temperature curves (figs. 4, 27, and 28) convinces one that they must have been mainly due to the presence of the carbon dioxide gas.

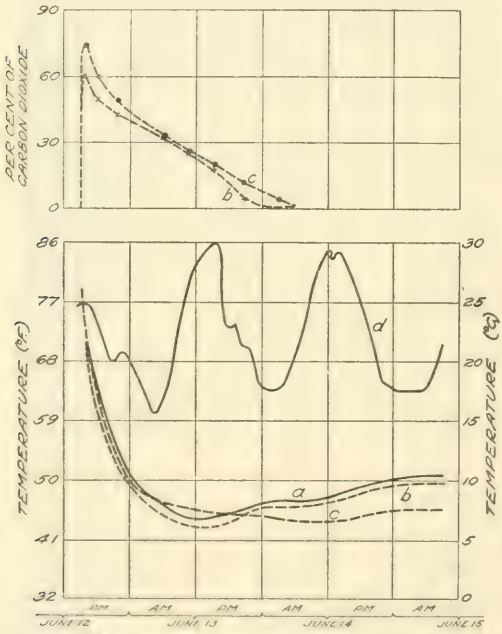

FIGURE 27.—Carbon dioxide curves and temperature curves in an experiment with dewberries in 80-quart pony refrigerators, June 12 to 15, 1929: *a*, Control refrigerator with 163 pounds of ice; *b*, refrigerator with 133 pounds of ice and 28 pounds of solid CO_2; *c*, refrigerator with 97 pounds of ice and 28 pounds of solid CO_2; *d*, outside temperature. The refrigerator in *c* was not of standard construction and has been described in the legend to Figure 6. The temperatures shown are the averages of records from the top and bottom layers of baskets

DEWBERRIES IN REFRIGERATOR CARS

The car-lot shipments of dewberries were carried out as already described for strawberries. The results are shown in Table 9 and in Figures 29 to 33, inclusive.

TABLE 9.—*Condition of dewberries and dewberry-rot organisms in standard refrigerator cars with different methods of cooling*

Figure reference [1]	Location in car	Flavor of berries in—			Soft berries in—			Rotten berries in—			Increase in diameter of colonies of rot organisms in Petri dishes					
											Gloeosporium in—			Rhizopus in—		
		Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car
					Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*
Fig. 29	Top center	Good		Good			16.1			6						
	Top bunker	do		do	[2] 10.5		19.2	[2] 7.7		7.8						
	Average top of car				10.5		17.7	7.7		6.9						
	Bottom center	Good		Good	[2] 6.6		15.9	[2] 4.5		5.3						
	Bottom bunker	do		do	[2] 7.1		12.1	[2] 3.3		2						
	Average bottom of car				6.9		14	3.9		3.7						
	Average for car				8.7		15.8	5.8		5.3						
Fig. 30	Top center	Good		Good	12.6		18.6	1.2		7.9						
	Top bunker	do		do	10.5		13.6	2.8		3.1						
	Average top of car				11.6		16.1	2		5.5						
	Bottom center	Good		Good	6.8		15.1	1.1		1.7						
	Bottom bunker	do		do	9		10.2	.5		1.4						
	Average bottom of car				7.9		12.7	.8		1.6						
	Average for car				9.7		14.4	1.4		3.5						
Fig. 31	Top center	Good		Good	7.5		13.1	1.7		5.8						
	Top bunker	do		do	7		9.3	3.5		2.7						
	Average top of car				7.3		11.2	2.6		4.3						
	Bottom center	Good		Good	9.6		13.1	1.6		2						
	Bottom bunker	do		do	4.8		7.5	.9		.5						
	Average bottom of car				7.2		10.3	1.3		1.3						
	Average for car				7.2		10.8	1.9		2.8						
Fig. 32	Top center	Good	Good	Good	9.1	16.4	10.9	0	0.8	.9	9.5	10.5	13.5	6	5.2	25.5
	Top bunker	do	do	do	7.9	15	18.1	1.1	.2	2.3	8.5	15.2	14.5	7	23	16
	Average top of car				8.5	15.7	14.5	.6	.5	1.6	9	12.9	14.	6.5	14.1	20.8
	Bottom center	Good	Good	Good	10.9	10.3	3.7	0	.3	.3	6	8.5	8.5	0	.3	1.5
	Bottom bunker	do	do	do	10.4	11.9	7.5	2.9	.2	.7	2	5	5.5	0	0	0
	Average bottom of car				10.7	11.1	5.6	1.5	.3	.5	4	6.8	7	0	.2	.8
	Average for car				9.6	13.4	10.1	1	.4	1.1	6.5	9.8	10.5	3.3	7.1	10.8

[1] For data on temperature, CO_2, and length of treatment, see Figs. 29 to 33, inclusive.
[2] Record after 20 hours' exposure to outside temperature. See legend for Fig. 29.

TABLE 9.—*Condition of dewberries and dewberry-rot organisms in standard refrigerator cars with different methods of cooling*—Continued

Figure reference	Location in car	Flavor of berries in—			Soft berries in—			Rotten berries in—			Increase in diameter of colonies of rot organisms in Petri dishes					
											Gloeosporium in—			Rhizopus in—		
		Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car	Carbon dioxide car	Blower car	Control car
					Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*
Fig. 33	Top center	Good	Good		13.9	22.6		.7	1.5		7.5	10.7		[3] 45.7	[3] 59	
	Top bunker	do	do		20.3	34.6		1.6	10.5		11	13.5		[3] 63.3	[3] 76.5	
	Average top of car				17.1	28.6		1.2	6		9.3	12.1		54.5	67.8	
	Bottom center	Good	Good		12.4	20.8		1	1.7		6	5.5		[3] 35	[3] 31.5	
	Bottom bunker	do	do		16.1	14.5		.7	1.9		5	3.5		[3] 16	[2] 6.8	
	Average bottom of car				14.3	17.7		.9	1.8		5.5	4.5		25.5	19.2	
	Average for car				15.7	23.1		1	3.9		7.4	8.3		40	43.5	
Average of Figs. 30 to 32.	Top of car				9.1		13.9	1.7		3.8						
	Bottom of car				8.6		9.5	1.2		1.1						
	Average for car				8.8		11.8	1.4		2.5						
Average of Figs. 32 and 33.	Top of car				12.8	22.2		.9	3.3		9.2	12.5		30.5	41	
	Bottom of car				12.5	14.4		1.2	1.1		4.8	5.7		12.8	9.7	
	Average for car				12.7	18.3		1	2.2		7	9.1		21.7	25.3	

[3] Inoculations were made 20 hours before loading.

The flavor of the berries was tested at destination, and sample lots were returned to Washington, D. C., for further tests. In no instance could any change in flavor be detected.

In the shipment reported in Figure 29, the control car arrived a day later than the test car. The records for the test car were taken after the fruit had been exposed to an outside temperature of more than 70° F. for 20 hours, whereas those for the control car were taken immediately after unloading. Despite this difference in treatment, the control car showed practically the same percentage of rot as the test car and a far higher percentage of soft berries.

In the shipments described in Figures 30, 31, and 32, the different cars were unloaded at practically the same time; the records show 25 per cent less soft berries and 42 per cent less rotten berries in the test car than in the control car.

The average percentage of soft berries for the top of the carbon dioxide cars was lower than the average for the bottom of the control cars. The average percentage of rotten berries in the top of the test cars was about halfway between the average for the bottom of the control cars and the total average for the control cars. Converting these results into temperature values on the basis of the temperature curves of the control cars, as has been outlined in the discussion for strawberries and peaches, it is found that the solid carbon dioxide had an effect upon the softening of the fruit in the top of the car equal to that of a reduction of 14° F. in temperature during the entire trip, and an effect upon the rots in the top of the car equal to that of a 10° reduction in temperature during the entire trip. If it is assumed that the action of the solid carbon dioxide was confined to the first 36 hours after loading, it is estimated that during this period there was an inhibiting effect upon the softening of the fruit approximately equal to that of an average reduction in temperature of 26° and of a retarding action upon the rots equal to a 19° reduction in temperature.

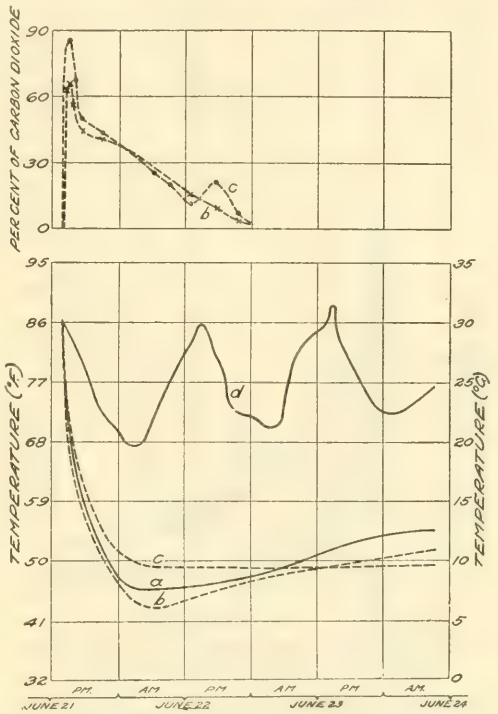

FIGURE 28.—Carbon dioxide curves and temperature curves in an experiment with dewberries in 80-quart pony refrigerators, June 21 to 24, 1929: *a*, Control refrigerator with 170 pounds of ice; *b*, refrigerator with 133 pounds of ice and 35 pounds of solid CO_2; *c*, refrigerator with 101 pounds of ice and 36 pounds of solid CO_2; *d*, outside temperature. The refrigerator in *c* was the same as described under *c* of Figure 6. The temperatures shown are the averages of records from the top and bottom layers of baskets

The temperatures in the tops of the test cars were usually lower than those in the tops of the control cars, but always far above the temperatures in the bottoms of the control cars, indicating that the reduction in softening and decay in the test cars must have been largely due to the presence of the carbon dioxide gas.

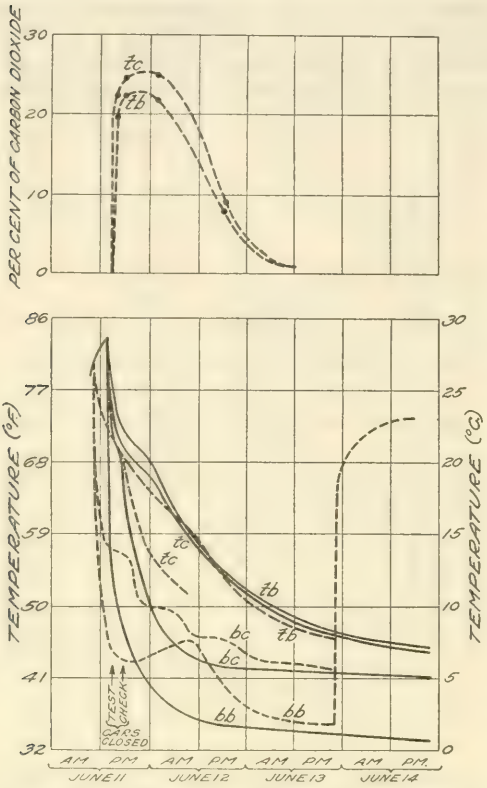

FIGURE 29.—Carbon dioxide curves and temperature curves in an experiment with dewberries shipped in standard refrigerator cars from Hamlet, N. C., June 11, 1928. The broken lines give the records for the carbon dioxide car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to standard icing, 815 pounds of solid CO_2 held on a scaffold in the center of the car about 16 inches above the load. The control car required 2,340 pounds more ice at the reicing stations than the test car, not including an extra 800 pounds that was added on account of the delay in unloading the control car. Each car contained 224 crates of berries

Sample lots of fruit were held at outside temperature for several days after removal from the cars, and it was found that the differences in firmness and decay at the time of unloading were fully maintained under marketing conditions.

In the shipment described in Figure 32 a blower or precooled car was used for comparison with a carbon dioxide car and a control car. In the shipment indicated in Figure 33, a similarly precooled car was used for comparison with a carbon dioxide car. In the first shipment there were more soft berries in the blower car than in the control car, and in the second shipment as many soft berries in the bottom of the blower car as in the top of the carbon dioxide car. In some instances the inhibition of the rot organisms was greater in the carbon dioxide car and in other instances greater in the blower car; but if an average of the two cars is taken the results show a greater inhibition in the carbon dioxide car in all cases. The average inhibition of rots in the top of the carbon dioxide cars was about the same as that for the entire blower cars.

EXPERIMENTS WITH OTHER FRUITS AND WITH VEGETABLES

BLACKBERRIES

Small lots of blackberries were included in the tests described in Figures 3, 15, 19, and 20. The flavor of the fruit remained unaffected under all the conditions of these experiments, whereas, as already

pointed out in Table 6, the flavor of peaches under certain of these conditions was spoiled. (See fig. 19.)

Experiments were also made in which blackberries were held at constant temperatures of 50° and 68° in maintained atmospheres containing 40 per cent of carbon dioxide. The flavor of the fruit was normal after treatment for 2 days and doubtful at 68° after 3 days and at 50° after 5 days. The results indicate that blackberries will stand much longer exposure to high percentages of carbon dioxide than peaches or strawberries, yet it is evident that there is a definite limit to their tolerance.

RASPBERRIES

Small lots of red raspberries were included in the tests indicated in Figure 27, and small lots of both red and black raspberries were included in the tests reported in Figure 28. Under the carbon dioxide treatments described for these experiments the flavor of the red raspberries was affected as much as that of the strawberries included in the same tests, whereas the flavor of the black raspberries was unaffected.

BLUEBERRIES

Wild blueberries were held at constant temperatures of 50° and 68° F. in maintained atmospheres containing 40 per cent of carbon dioxide. The test at 68° was continued for six days and that at 50° for eight days, but no change in the flavor of the fruit could be detected as a result of the carbon dioxide treatment.

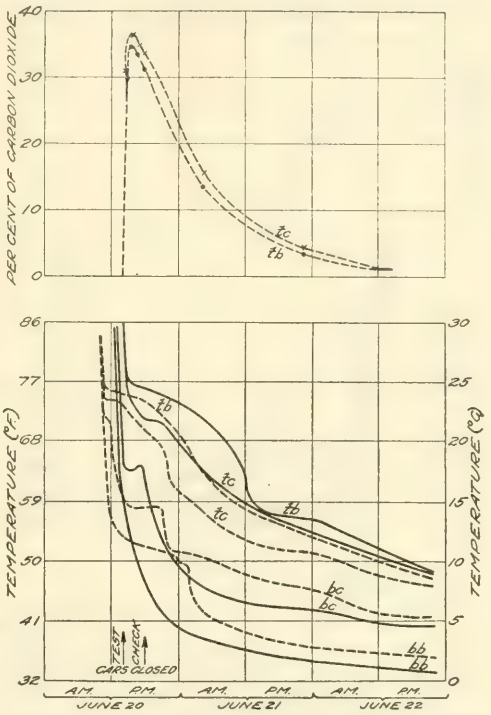

FIGURE 30.—Carbon dioxide curves and temperature curves in an experiment with dewberries shipped in standard refrigerator cars from Hamlet, N. C., June 20, 1928. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to standard icing, 940 pounds of solid CO_2 held on a scaffold in the center of the car about 16 inches above the load. The control car required 1,500 pounds more ice at the reicing stations than the test car. The control car carried 190 crates of berries, the test car 224 crates

CURRANTS

Small lots of currants were included in the tests reported in Figure 28. The flavor remained normal under all the conditions described.

APRICOTS

Apricots were included in the tests described in Figure 28. At the end of the experiment it was found that their flavor had been

affected by the carbon dioxide treatments fully as much as that of the peaches and red raspberries.

CHERRIES

Early Richmond cherries were included in the tests reported in Figure 3, Blackheart cherries in those in Figure 27, and Bing and Montmorency cherries in the tests described in Figures 27 and 28. None of the carbon dioxide treatments in these various experiments had any evident effect upon the flavor of either the sweet or the sour varieties.

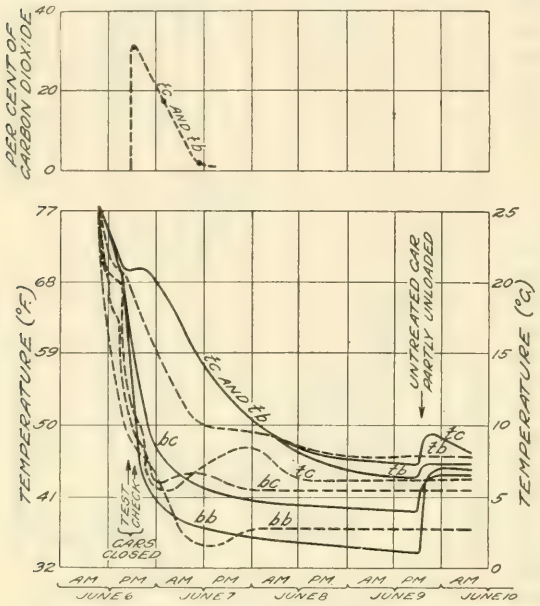

FIGURE 31.—Carbon dioxide curves and temperature curves in an experiment with dewberries shipped in standard refrigerator cars from Cameron, N. C., June 6, 1929. The broken lines give the records for the test car, the solid lines the records for the control car: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The test car received, in addition to the usual bunker icing, 1,000 pounds of solid CO_2 held on a scaffold in the center of the car about 16 inches above the load. The test car received 2 per cent of salt at the shipping point. Each car contained 224 crates of berries

Windsor cherries were held at 68° and 50° F. in maintained atmospheres containing 40 per cent of carbon dioxide. At 68° the cherries in carbon dioxide had a normal flavor, as compared with the controls, at the end of five days, but were slightly insipid at the end of six days. The experiment at 50° was discontinued at the end of eight days, with the flavor of the cherries in carbon dioxide still entirely normal.

Bing cherries were exposed to 40 per cent of carbon dioxide for two days at 32°, 41°, 50°, 59°, and 68° F., without any impairment of flavor as compared with the controls. A part of the cherries from the various lots had been inoculated with Monilia when the experiment was started and were held at 50° in normal atmosphere after the end of the 2-day treatment. It was found that the rots on the cherries that had been held in carbon dioxide at 68° and 50° were much smaller than those on the controls held at a temperature 18° lower, and that the rots on the cherries held in carbon dioxide at 50° were only slightly larger than those on the controls held at 32°.

PLUMS AND PRUNES

Wickson plums, purchased on the Washington market, were exposed to 40 per cent of carbon dioxide for 48 hours at 32°, 41°, 50°, 59°, and 68° F. without any impairment of flavor. A part of the fruit had been inoculated with Monilia, and after the 2-day treatment

the different lots were removed from the various temperatures and stored at 50° in normal atmosphere. It was found that the rots on the plums that had been held in carbon dioxide at 68°, 59°, and 50° developed several hours later than those on the controls at temperatures 18° lower and that the rots on the fruit held in carbon dioxide at 50° were practically identical in size with those on the controls held at 32°.

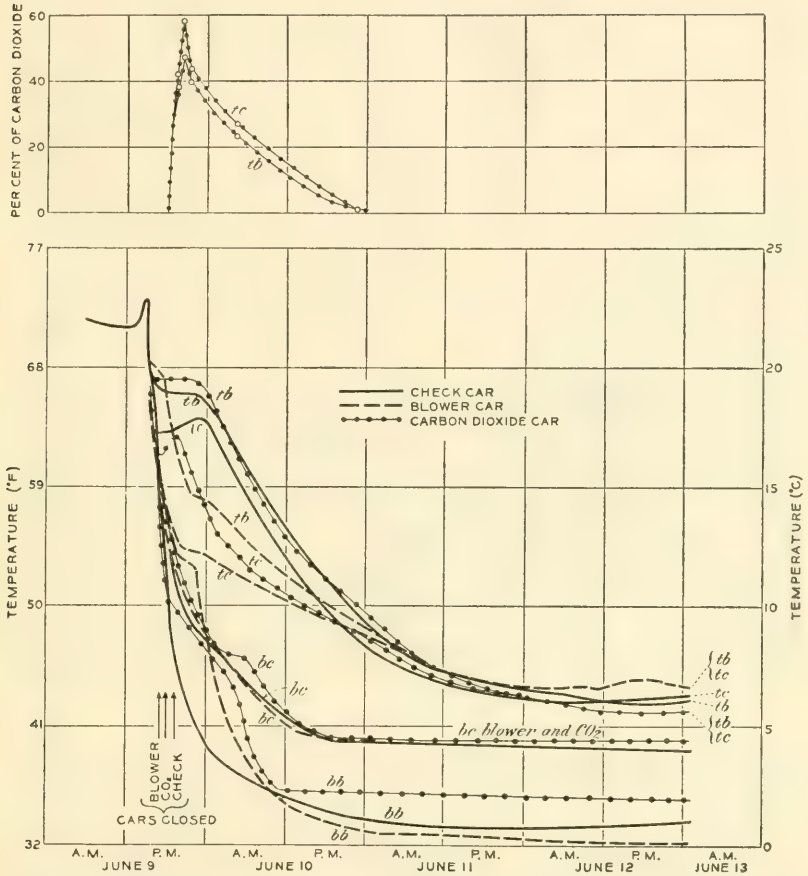

FIGURE 32.—Carbon dioxide curves and temperature curves in an experiment with dewberries shipped in standard refrigerator cars from Cameron, N. C., June 9, 1930: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The carbon dioxide car received 700 pounds of solid CO_2 placed on a scaffold about 16 inches above the load. The carbon dioxide car received 2 per cent of salt at the shipping point and the blower car 3 per cent. Each car carried 280 crates

Italian Prunes, purchased on the Washington market, were exposed to 50 per cent carbon dioxide under constant-temperature conditions. In one experiment fruit held at a temperature of 66° F. had become rather insipid by the end of 7 days, but that held at 48° had retained its normal flavor at the end of 17 days. In another experiment fruit retained its normal flavor at 67° for 13 days and at 49° for 17 days, but later developed a dry and slightly objectionable taste at both temperatures.

In the summer of 1930 pony-refrigerator experiments were made at Wenatchee, Wash., with fresh Italian Prunes that had just been picked at a proper stage of maturity for commercial shipment. The refrigerators were of the type described in the legend of Figure 6 and had capacity of 4 bushels. Half the storage space was filled with Italian Prunes and half with Bartlett pears. Two refrigerators were loaded and iced exactly alike, but one of them received

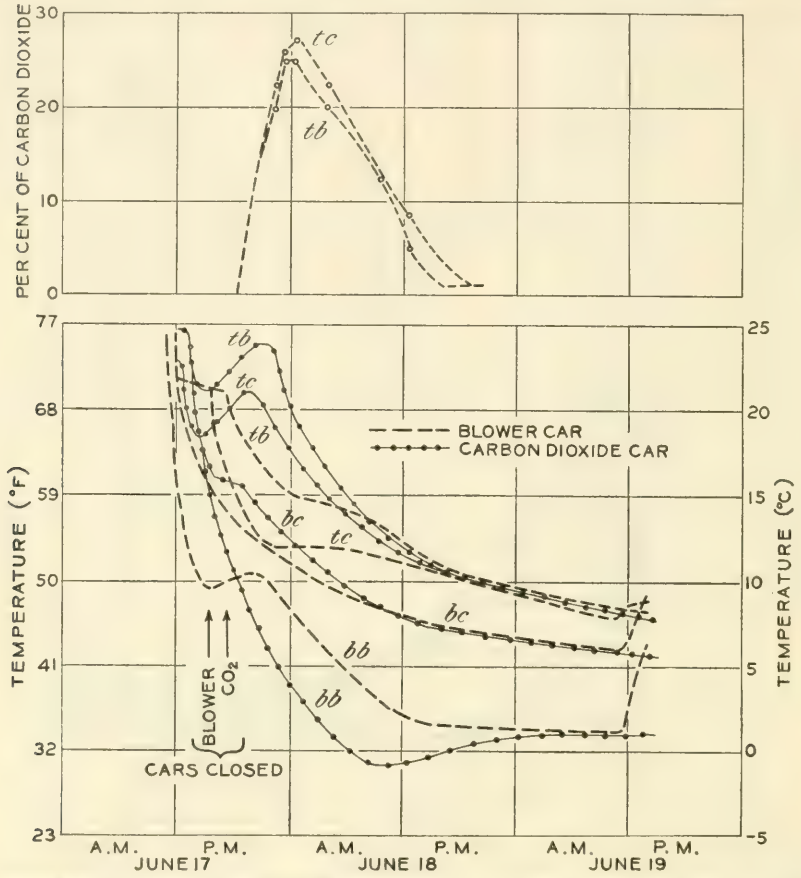

FIGURE 33.—Carbon dioxide curves and temperature curves in an experiment with dewberries shipped in express refrigerator cars from Cameron, N. C., June 17, 1930: *tc*, Top center; *tb*, top bunker; *bc*, bottom center; *bb*, bottom bunker. The low temperature at the bottom bunker of the carbon dioxide car may have been due to air currents resulting from a defective water trap. The carbon dioxide car received 530 pounds of solid CO_2 placed on a scaffold about 16 inches above the load. The blower car received 400 pounds of salt at the shipping point and the carbon dioxide car 315 pounds. Each car carried 280 crates

a continuous stream of carbon dioxide gas from a carbon dioxide cylinder. The experiments were carried out in a laboratory where the temperature ranged between 70° and 80° F., averaging about 75°. In the first experiment the fruit in the control refrigerator was cooled to 52° in about 24 hours with little further change in temperature; in the second experiment it was cooled to 55° in 24 hours and fell to 50° before the end of the experiment. The fruit in the carbon

dioxide refrigerator was usually about 2 degrees warmer than that in the control refrigerator.

The carbon dioxide was run rapidly into the test refrigerator for a half hour; the rate was then decreased until it balanced that of the leakage from the refrigerator. In the first experiment the carbon dioxide in the refrigerator was held at approximately 30 per cent for the first 6 hours and at 20 per cent for the next 42 hours; in the second experiment it was held at approximately 15 per cent for the first 8 hours, at 12 per cent for the next 64 hours, and tapered off to 3 per cent by the end of the fourth day.

In the first experiment a part of the fruit was removed from the refrigerators at the end of 1 day, and the remainder at the end of 2 days; in the second experiment a part of the fruit was removed at the end of 2 days, and the remainder at the end of 4 days.

After removal from the refrigerators the fruit was held at laboratory temperatures. The prunes from the carbon dioxide refrigerator were firmer than the others and ripened more slowly; in order to bring the two lots to a like maturity, it was necessary to hold the control fruit in a refrigerator at 45° F. for several days, while the test fruit was exposed to an outside temperature of 75°.

When fully ripened, no difference in flavor could be detected between the fruit receiving any of the carbon dioxide treatments and that which had been held in the control refrigerator.

In both experiments needle inoculations were made with Monilia and Rhizopus, as described for peaches. In the first experiment the inoculated prunes were removed from the refrigerator and placed at the outside temperature at the end of 1 day, in the second experiment at the end of 4 days. In both experiments and with both fungi, the rots on the fruit from the carbon dioxide refrigerator were a full day later than those on the fruit from the control refrigerator, the 1-day treatment under the conditions of the first experiment causing somewhat greater delay than the 4-day treatment under the conditions of the second experiment.

PEARS

As already mentioned, half the refrigerator space in the experiments described above was given to Bartlett pears. The pears had been picked less than 24 hours before the experiments were started. Those of the first experiment showed a pressure resistance of 17 pounds and those of the second experiment a resistance of 15.6 pounds.

In both experiments pears were inoculated with *Botrytis cinerea*, held in the refrigerators the full period of the test, and then removed to room temperature. In both instances the rots on the fruit from the carbon dioxide refrigerator were found to be almost exactly two days later than those on the fruit from the control refrigerator, indicating that the rots were held completely in check in the 2-day treatment of the first experiment but were not completely inhibited with the lower percentage of gas in the 4-day treatment of the second experiment.

In order to determine the effect of the carbon dioxide treatments upon flavor and keeping quality, some of the pears were held in a warm room for immediate ripening and the remainder placed in storage at 32° F. Sample lots were removed from storage on September 15 and October 11 and shipped to Washington, D. C., by ordinary express; larger lots were removed to the Wenatchee laboratory on October 16 and 24. In all cases the fruit that had been subjected to carbon dioxide was found to be firmer and to have less yellow in the ground color than that from the control refrigerators. The treated pears that were removed from storage October 16 and 24 showed an average resistance to pressure of 15.5 pounds and the untreated ones a resistance of 12.2 pounds. When the different lots were held under suitable temperature conditions to bring them to a like maturity no difference in flavor could be detected between the treated and untreated fruit, regardless of whether ripened immediately or held in storage. When the different lots were held at room temperature for six days after removal from storage it was found that the control fruit had a much higher percentage of internal breakdown and several times as many rots as the fruit that had been exposed to carbon dioxide.

A third experiment was made with Bartlett pears in pony refrigerators, but with the treated fruit inclosed in 9-quart jars. The experiment was continued 64 hours, and 10 different carbon dioxide treatments were given, varying in percentage of gas and in period of exposure, and ranging all the way from 25 per cent for 12 hours to 25 per cent for 24 hours, followed by 45 per cent for 40 hours. After removal from the experiment the pears were stored and sampled, as described above. No difference in flavor could be detected between the treated and untreated fruit. The pears of this experiment were slightly more mature than those of the first two experiments.

Pony-refrigerator experiments, similar to those already reported for Italian Prunes and Bartlett pears, were made with Anjou pears and Jonathan apples. The fruit was cooled somewhat more slowly than in the previous experiments and the temperature in the carbon dioxide refrigerator averaged about 5° F. higher than that in the control refrigerator. The carbon dioxide content of the air in the test refrigerator was maintained at practically 20 per cent throughout the experiment. Part of the fruit was removed at the end of one day and the remainder at the end of two days; each lot was taken immediately to cold storage. Sample lots of the fruit were removed from storage on October 11 and shipped to Washington, D. C., by ordinary express; the remainder was removed to the Wenatchee laboratory on November 10.

It was extremely difficult to decide upon the flavor of the different lots of Anjou pears, as slight differences in maturity had a greater determining value than the carbon dioxide treatments and the variation within the lot was much greater than that between the lots; but, on the whole, the percentage of pears that were somewhat lacking in flavor and juiciness was apparently larger with the treated fruit than with the untreated. No distinction could be made between the fruit that had received the carbon dioxide treatment for one day and that which had received it for two days.

At the time of picking, the Anjou pears showed a pressure resistance of 13 pounds. When removed from storage the treated fruit

showed a resistance of 12.4 pounds and the untreated a resistance of 12.2 pounds. After three days in a warm room the treated fruit showed a resistance of 10 pounds and the untreated a resistance of 8.1 pounds.

A later picking of Anjou pears was made, and carbon dioxide treatments were given as described in the third experiment for Bartlett pears, with the same wide range in percentage of gas and period of exposure. The storing and sampling were carried out as described above for the Anjou pears. When fully ripe no difference could be detected between the flavor of the treated fruit and that of the untreated fruit. The pears of this experiment were slightly more mature than those of the preceding experiment, and it is possible that this accounts for the fact that they stood the more extreme treatments with no evidence of reduced flavor.

Seckel pears were included in the tests reported in Figures 16, 17, and 20, without impairment of flavor under any of the carbon dioxide treatments.

In another experiment Seckel pears were held for 11 days at 66° F. in an atmosphere containing 50 per cent of carbon dioxide, and for 17 days at 48° in a similar atmosphere, without impairment in flavor or other evident injury.

In the summer of 1931 pony-refrigerator experiments similar to those reported for berries and peaches were made with freshly picked Bartlett pears from the Hudson River Valley. The temperature in the different refrigerators was practically the same, dropping to 50° F. in about 24 hours and remaining between 45° and 52° the remainder of the time. After three days' treatment the pears were placed in storage at 32° F. Similar lots had been stored immediately at that temperature, and other lots were held at outside mean temperature of approximately 65° for the three days and then stored at 32°. After six weeks' storage it was found that fruit that had been exposed to an atmosphere in which the carbon dioxide content was about 50 per cent in the beginning and tapered off to 25 per cent at the end of 20 hours and to 10 per cent at the end of 30 hours was in better condition both as to firmness and as to the presence of internal breakdown than fruit that had been stored immediately at 32°. Pears that had been held in an atmosphere containing 50 to 75 per cent carbon dioxide in the beginning and tapering off to 25 per cent in 40 hours and to 10 per cent in 50 to 60 hours showed a resistance to pressure 50 per cent greater than the immediately stored fruit and had less than half as much internal breakdown. The fruit that was held at outside temperature for three days and that held in pony refrigerators without carbon dioxide for three days was much softer than the immediately stored fruit and had a far greater percentage of internal breakdown. No contrast in flavor was found between the pears from the different treatments when fruit of similar maturity was compared.

APPLES

As mentioned previously, Jonathan apples were included with the pears in the first Anjou experiment. The storing and sampling were carried out as already described in that experiment. In the fruit shipped to Washington, D. C., it was found that the differences within lots were greater than those between lots, yet on the whole the

treated fruit was firmer and had slightly less flavor and juiciness than the untreated. Among the apples removed to the Wenatchee laboratory no difference could be detected in flavor or quality.

The apples of the experiment described above were immature at picking time and came from orchards where the fruit is of notoriously poor quality. A second experiment was made with Jonathan apples that were more mature and of better quality. The carbon dioxide treatments were given as described in the third experiment with Bartlett pears, with the same wide range in the percentages of gas and in the periods of exposure. After being held in storage, as described for the Anjou pears, sample lots were shipped to Washington, D. C., and other lots were removed to the Wenatchee laboratory. The treated fruit was slightly firmer and made a better appearance than the untreated, and in all cases had fully as good flavor.

Yellow Newtown apples were subjected to the carbon dioxide conditions reported in Figure 25, without impairment of flavor.

In the fall of 1931 pony-refrigerator experiments similar to those reported for berries and peaches were made with freshly picked Grimes Golden and Delicious apples from Virginia and Jonathan apples from Maryland and from New York. After two days in the refrigerators the fruit was placed in storage at 30° to 32° F. with other lots that had been held at outside temperature. Additional lots were placed at 32° at the time of picking. After several months' storage the fruit that had been exposed to carbon dioxide was found to be in better condition as to firmness and freedom from soft scald and other diseases than fruit that had been placed immediately at 32°, while the fruit that had been delayed at outside temperature or held in refrigerators without carbon dioxide was found to be softer and to have a higher percentage of decay. No contrast in flavor was found between the apples from the different treatments when fruit of similar maturity was compared.

GRAPES

Several varieties of grapes were tested and all showed extreme tolerance of carbon dioxide. Cornichon grapes were included in the experiment of Figure 4, Sultanina (*Thompson Seedless*) grapes in the experiments of Figures 14 and 15, Catawba grapes in the experiment of Figure 16, and Concord and Malaga grapes in the experiment of Figure 20, with no apparent modification in flavor in any case.

Experiments were also made at the constant temperatures with maintained percentages of carbon dioxide. In one test Sultanina grapes were subjected to 40 per cent carbon dioxide at 68° F. for five days and at 50° for seven days, and the flavor was still normal at the end of the experiment.

In a second test Sultanina, Flame Tokay, Niagara, Delaware, and Concord grapes were held in 50 per cent carbon dioxide at 66° F., with no impairment in flavor at the end of 9 days, but with the first three varieties becoming overripe and somewhat insipid at the end of 12 days. Similar lots were held at 48°, with no impairment in flavor at the end of 15 days, but with the Flame Tokay and Concord

varieties noticeably insipid at the end of 17 days and the Delaware at the end of 20 days.

In a third experiment, Cornichon, Niagara, Concord, and Delaware grapes were held in 50 per cent carbon dioxide at 67° F., with good flavor at the end of 11 days and nothing more objectionable than slight overripeness at the end of 13 days. Similar lots held at 49° retained good flavor at the end of 17 days, but were slightly overripe and losing flavor at the end of 20 days.

In a fourth experiment, started later in the season (October 30), Flame Tokay and Concord grapes were held in 50 per cent carbon dioxide for eight days at 68° and 50° F. At the end of the experiment the flavor of the Flame Tokay grapes was good at both temperatures, and that of the Concord was good at 50° but slightly off at 68°.

In the last experiment, part of the grapes of each variety were inoculated with Botrytis before the test was started. At the end of eight days the control lots had 100 per cent of infection at 68° F. and about 90 per cent of infection at 50°, whereas the grapes held in 50 per cent carbon dioxide were entirely free from rot at both temperatures. The experiment indicates that the use of solid carbon dioxide should make it possible to greatly reduce grape rots in transit without affecting the flavor of the fruit.

In storage experiments carried out in the fall of 1931 it was found that shattering could be greatly reduced on Moore Early, Niagara, Concord, Worden, Delaware, and Golden Muscat grapes by a day's exposure to carbon dioxide gas. In most cases the period that the fruit could be held without shattering was doubled by the carbon dioxide treatments.

ORANGES AND MANGOS

Oranges and mangos were included in the tests reported in Figure 25. The carbon dioxide treatments of this experiment had no evident effect upon the flavor of either of these fruits.

TOMATOES, STRING BEANS, AND PEAS

Small lots of ripe tomatoes were included in the tests reported in Figure 26. The carbon dioxide treatments described for this experiment had no evident harmful effect upon the tomatoes.

In one experiment string beans were held at 68° F. in 46 per cent carbon dioxide for 24 hours; in another experiment string beans and peas were held at 72° in 30 per cent carbon dioxide for 48 hours, without impairment in flavor or condition.

CORN, CARROTS, AND CAULIFLOWER

Sweet corn was included in the tests reported in Figures 15, 17, 19, and 26. It was also included in the test in which beans were exposed to 46 per cent carbon dioxide for 24 hours at 68° F.; in other tests it was exposed to 40 per cent carbon dioxide for 48 hours at 32°, 41°, 50°, 59°, and 68°. Several different varieties of sweet corn were used, and in all cases the corn that had been subjected to carbon dioxide was fresher and sweeter at the end of the storage test than that which had been held in normal air. Its superior condition was evident after cooking as well as before.

Carrots and cauliflower were held in 30 per cent carbon dioxide at 72° F. for 48 hours. At the end of the experiment both the green and the edible parts of these treated products were much fresher in appearance than were those of similar untreated ones. The carrots and cauliflower that had been subjected to carbon dioxide were much sweeter than the controls. This was evident before cooking and still more so afterwards. When cooked the treated carrots were distinctly superior to the untreated. The treated cauliflower showed a slight reduction in flavor or odor that made the question of quality a matter of personal preference.

DISCUSSION

As pointed out in the beginning (p. 1) the present investigation was undertaken with the hope of finding at least a partial remedy for the spoilage that results from the warm condition of fruit during the first hours after loading for shipment. The studies that have been reported emphasize the hazards that must be met in attempting to secure such a remedy by means of treatment with carbon dioxide. In order to give satisfactory inhibition of the rots it has been found desirable to have a concentration of carbon dioxide approaching 25 per cent, but experiments have shown that the exposure of peaches or strawberries to 25 per cent of carbon dioxide gas for as long a period as 24 hours is liable to affect the flavor, especially if the fruit is held at the usual summer temperatures. This leaves but little margin for safety. By using solid carbon dioxide in sufficient quantities to insure the escape of most of the carbon dioxide gas from the car within 24 hours, it has been found possible to make four experimental shipments with strawberries and five with peaches in which a very significant reduction in rots and in the softening of the fruit was obtained without any appreciable effect upon the flavor of the fruit. Certain precautions were taken, however, which would be impracticable in commercial shipments. The shipments were followed in transit and frequent records taken of the gas concentration. Moreover, the cars were examined in advance, and allowance was made for tightness and newness of construction. In some instances a part of the solid carbon dioxide was placed in the bunker, on top of the ice, so that it could be conveniently removed if there was an indication of excess treatment.

Despite its practical difficulties, it should be noted that, as compared with other methods of protecting the fruit during the first hours after loading, the carbon dioxide method has made a particularly good showing, indicating that even if the quantity of solid carbon dioxide was considerably reduced the treatment would still be more effective than any convenient method of precooling now available. Such a reduction would decrease the cost of the treatment as well as increase its safety. With the products mentioned in this bulletin, aside from peaches, apricots, strawberries, and red raspberries, this reduction would apparently be unnecessary, and in fact the tolerance tests indicate that in many instances the severity of the treatment might be increased, if found desirable.

The efficacy of the carbon dioxide treatment is shown in Figure 34. The solid-line curves of this figure give the average of the tempera-

tures that prevailed in the control cars in 13 refrigerator-car experiments—4 with strawberries, 5 with peaches, and 4 with dewberries. The broken lines in the lower half of the figure give the approximate temperatures that would have been required in the top of the test cars to have secured the inhibition obtained by the use of solid carbon dioxide. The effect of the treatment upon the softening of the fruit in the top of the car was such as to justify a hypothetical temperature curve below the average for the bottom of the control cars. The effect upon the rots in the top of the test car was sufficient to bridge about 75 per cent of the gap between the results in the top and the bottom of the control cars and to require a temperature curve almost identical with that for the bottom center of the control cars, averaging approximately 10 degrees lower than the curve for the top of the control cars.

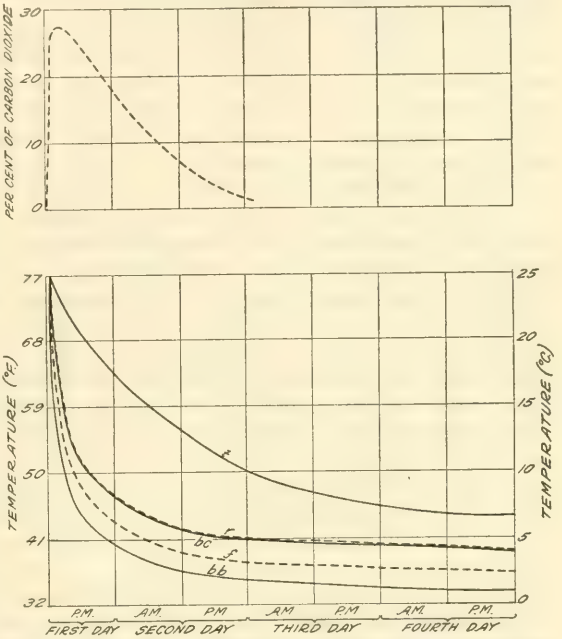

FIGURE 34.—Curves showing average carbon dioxide and temperature conditions in 13 refrigerator-car shipments—4 with strawberries, 5 with peaches, and 4 with dewberries. The upper curve gives the average percentage of CO_2 gas where solid CO_2 was used. The solid lines of the lower curves give the average temperatures in the control cars: *t*, Top of car; *bc*, bottom center; *bb*, bottom bunker; *r*, approximate temperatures that would have been required in the top of the test cars to have produced the effects upon the rots that were actually obtained by the supplementary use of solid CO_2; *f*, a similar record for the effects upon the rate of softening of the fruit

The hypothetical temperature curves indicate the value of the carbon dioxide treatments, but it is not considered that they give a proper picture as to the time when the inhibition actually occurred. Within a half hour to an hour after loading the carbon dioxide gas had mounted to a percentage that should cause an inhibition of the rots equal to that resulting from a drop in temperature of 20° to 40° F.; this inhibition probably continued in varying degrees from 12 to 36 hours, leaving the control of the rots during the latter part of the shipping period to be determined largely by temperature. The quickness with which the action of the carbon dioxide can be made effective is an important point in its favor.

Mention has been made of the fact that the carbon dioxide treatments seem to favor the preservation of the sugar content. Chemical studies are in progress on this phase of the problem.

SUMMARY

Various fruits and vegetables have been subjected to different percentages of carbon dioxide, under a variety of temperature conditions, with the object of finding a method of decreasing the spoilage that occurs in the first 24 to 36 hours after loading a warm product in a refrigerator car. The control of diseases and other forms of spoilage has been readily accomplished, but the effect of the carbon dioxide upon the flavor of the product has been found to set definite limitations to this method of treatment.

The most serious limitations have been found with peaches, apricots, strawberries, and red raspberries. Plums, cherries, blackberries, blueberries, black raspberries, currants, pears, apples, and oranges have shown a greater tolerance of the gas. Grapes, peas, sweet corn, and carrots have stood extreme treatments with particularly favorable results.

The first objectionable effect resulting from excessive carbon dioxide treatments was a slight loss of aroma. With more prolonged or severe treatments, this was followed by a still greater loss of flavor and sometimes by the development of an odor of fermentation or other objectionable quality. Products having a definite and characteristic aroma were the most easily affected.

High percentages of carbon dioxide were more harmful than lower ones; yet, with 25 per cent or more of the gas, increase in concentration did not greatly shorten the period of safe treatment.

The effect of the carbon dioxide upon the flavor increased with an increase in temperature in a manner that indicated a relationship with general metabolic activities. Exposure of peaches to 25 per cent or more of carbon dioxide for 1 day at 77° F. had about the same effect upon flavor as 2 days' exposure at 59°, 3 days' exposure at 50°, or 4 days' exposure at 41°.

The flavor of peaches and strawberries remained normal in pony-refrigerator and other experiments where the carbon dioxide content of the air had fallen to 25 per cent by the end of 12 hours and to 10 per cent within 24 hours, but in cases where this treatment was greatly exceeded there was often a question in regard to flavor. Apricots and red raspberries showed a similar susceptibility to injury, while all the other products that were tested showed a much greater tolerance of carbon dioxide, most of them a tolerance two to six times as great.

With strawberries at temperatures ranging from 32° to 77° F., Botrytis and Rhizopus rots were fairly well inhibited by 23 per cent of carbon dioxide and completely inhibited by 37 per cent or more of the gas. Botrytis inoculations on Bartlett pears and Monilia inoculations on Italian Prunes were held completely in check by 20 to 30 per cent of carbon dioxide and greatly inhibited by 12 to 15 per cent.

In a series of experiments with Monilia inoculations on peaches it was found that within the range of 10 to 50 per cent of carbon dioxide the average reduction in efficiency of the fungus was approximately twice that of the percentage of gas used. At 77° F., within a range of 10 to 40 per cent, the carbon dioxide had an effect upon Monilia rot approximately equivalent to that of reducing the

temperature as many degrees as the percentage of gas used. At lower temperatures the reduction in the efficiency of the fungus was equally great, if not greater, but the equivalent temperature reduction was necessarily less.

Carbon dioxide was even more efficient in checking the softening of the fruit than in preventing the development of rots. With 25 per cent or more of the gas the softening of strawberries was almost completely inhibited, and the softening of warm peaches was as greatly checked as by a drop in temperature of 18 degrees or more.

In pony-refrigerator experiments, Bartlett pears and Grimes Golden, Jonathan, and Delicious apples were held as firm and as free from disease by initial carbon dioxide treatments as by immediate storage at 32° F.

Carbon dioxide treatments have been found of value in preventing the shattering of grapes.

Sweet corn, cauliflower, peaches, and carrots that had been exposed to carbon dioxide were found to be distinctly sweeter than those held in normal air at the same temperature.

Fourteen refrigerator-car experiments were made in which solid carbon dioxide was used as a supplementary refrigerant and as a source of carbon dioxide gas. Four of these were with strawberries, five with peaches, and five with dewberries. In one instance the carbon dioxide content of the air remained below 10 per cent, and in another instance it stood at about 15 per cent for several hours and fell below 10 per cent at the end of 12 hours; but in most cases it was above 20 per cent for 5 to 12 hours and above 10 per cent for 15 to 24 hours.

These carbon dioxide treatments had no objectionable effect upon flavor, but in two peach shipments that received the maximum treatment a slight change in flavor could be detected when the fruit was held till fully ripened.

The carbon dioxide treatments had an average effect upon the rots in the top of the car equivalent to a lowering of 10° F. in temperature throughout the trip, or to an average lowering of temperature of 21° during the first 36 hours of the trip.

The fruit in the top of the test cars showed greater firmness at destination than the fruit in the bottom of the control cars, despite the fact that the temperature in the bottom of the control cars averaged about 13° F. lower than the temperature in the top of the same cars.

The carbon dioxide treatments had a favorable effect upon the fruit in the bottom of the test car, as compared with fruit in a similar position in the control car; but in both cases this fruit was already well protected by the usual methods of cooling.

Under the conditions of the shipping experiments reported, the inhibiting effect of the solid carbon dioxide has been almost entirely due to the carbon dioxide gas, the refrigerating effect of the solid carbon dioxide being largely offset by a slower melting of the ice in the bunkers.

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60

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UNITED STATES DEPARTMENT OF AGRICULTURE
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A CRITICAL LABORATORY REVIEW OF METHODS OF DETERMINING ORGANIC MATTER AND CARBONATES IN SOIL

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CONTENTS

	Page		Page
Introduction	1	Loss on ignition	18
The hydrogen peroxide method	2	Experimental data	18
Experimental data	3	Comparison of the methods	21
The combustion method	14	Summary	23
The organic factor	14	Literature cited	23

INTRODUCTION

The Division of Soil Chemistry and Physics of the Bureau of Chemistry and Soils has for some years used hydrogen peroxide as a part of the procedure of the method of mechanical analysis of soils. This method is based on the international method, essentially the British official method (*1*),[1] and is modified for our own purposes as described by Olmstead, Alexander, and Middleton (*16*). The hydrogen peroxide is primarily employed to secure increased dispersion by removing the organic matter. If the treatment with hydrogen peroxide may be so carried out as also to furnish an accurate estimate of the total organic matter in the soil, the mechanical analysis would have added value.

That the hydrogen-peroxide method has certain very definite limitations was pointed out by W. O. Robinson (*22*) in the paper in which the method was first suggested. It seemed very desirable to make a new study of the method in the hope of removing these limitations.

In the course of the study the other methods which are in use for the purpose of estimating organic matter came up for comparative study, and the investigation eventually assumed the form of a critical examination of these methods. The discussion and data given herewith are the results of that study.

Essentially four methods for estimating the amount of organic matter in the soil have been suggested and used. They are as follows: The loss on ignition (with a variant), the combustion method (with

[1] Italic numbers in parentheses refer to Literature Cited, p. 23.

many variants), the calculation of the organic matter from the quantity of nitrogen present, and the hydrogen peroxide method. These are by no means equally important or useful. The method based on an assumed constant nitrogen content of the soil organic matter has been repeatedly shown to be invalid. It appears to be true that in a given soil, and even in the soil of considerable areas, the carbon-nitrogen ratio ranges from 10 to 11.6 and therefore the organic matter-nitrogen ratio approximates 20 (*12, p. 90*). At the same time it is generally recognized that results based on these ratios are at best very rough approximations. This fact is brought out very clearly by Leighty and Shorey (*8*) who have found, in 172 samples of soil, carbon-nitrogen ratios ranging from a minimum of 3.5 to a maximum of 35.2, and by Middleton, Slater, and Byers (*15*) who have found, in the profiles of 8 soils and their colloids, an organic matter-nitrogen ratio ranging between the limits of 1.5 and 35.7. In view of these facts no further discussion of this relation will be presented.

THE HYDROGEN PEROXIDE METHOD

This method of estimation of the organic matter in the soil was proposed by W. O. Robinson (*22*) in 1927. The initial suggestion for the work came from the proposal by G. W. Robinson and Jones (*20*) in 1925 that hydrogen peroxide be used to determine the "degree of humification" of organic matter in the soil. This proposal was based on the assumption that unaltered plant tissue is not affected by hydrogen peroxide in the presence of soil mineral matter. W. O. Robinson was able to show that this assumption is not warranted in the case of soils and, by inference, that the inorganic soil material contains a catalyst (or perhaps catalysts) responsible for this effect. On this basis he developed a method which, in brief, consists in the treatment of a weighed portion of soil with a 15 per cent solution of hydrogen peroxide, heating on a water bath until effervescence ceases, and weighing the residual dried soil after filtration. The organic material of the soil is destroyed, or rendered soluble, by this process, and hence the difference between the dry weight of the soil and the dry weight of the residue represents the organic matter of the soil. Correction for dissolved inorganic matter was made by ignition of the evaporated filtrate.

The method offers a direct measure of the quantity of organic matter and is relatively so simple in procedure that if it is or could be made accurate and generally applicable its use would solve a very difficult problem. Unfortunately, as W. O. Robinson (*22*) himself pointed out, it has very serious limitations. Hydrogen peroxide does not remove all the carbon or carbon compounds from the soil. The residual carbon found after treatment with peroxide ranged from 0.04 to 1.90 per cent in the samples examined. It was believed that for the most part this residual carbon consists of adventitious charcoal, graphite, or paraffinlike bodies and is therefore not actually soil organic matter in the ordinary sense. Considerable experimental evidence is presented in justification of this view, especially in the cases of high residual carbon. This view of the matter is supported also by the previously published data of Schreiner and Brown (*26*) and by a subsequent paper by G. W. Robinson and McLean (*21*).

Further limitation of the method was shown in that the presence of any material quantity of manganese dioxide in the soil, because of its catalytic effect on the rate of decomposition of the peroxide, prevents the oxidation of the organic matter and, in the presence of considerable quantities of calcium or magnesium carbonates, the results are low and variable.

Since the publication of the method several papers which have a bearing on it have appeared. Waksman and Stevens (*32*) compared the effect of 6 per cent hydrogen and chlorine dioxide on sound chestnut wood, rotted wood, forest soil, and low-moor peat soil. They found the portions decomposed to vary from 20 to 80 per cent in the different materials, and they inferred that the hydrogen peroxide method was not suitable for such materials. In the light of Robinson's (*22*) work, it would seem that this result should have been expected and that the absence of soil mineral matter in such material is responsible for the low results. This is in harmony also with their own results which show that lignin from sound chestnut wood is even less subject to oxidation than the wood itself.

Shorey (*28*), while suggesting the use of hydrogen peroxide as a means of differentiation of soil organic matter by the use of 30 per cent hydrogen peroxide, shows that a very considerable fraction of the nitrogen of the soil remains in the insoluble residue, in peats, quantities as low as 4.9 per cent, and in soil low in organic matter, as high as 23 per cent. From his data it might be inferred that the residual nitrogen would bear a corresponding ratio to the total amount of organic matter present. Such an inference, if made, is unwarranted, since, as both he and Robinson (*22*) have shown, a very considerable fraction of the nitrogen of organic matter is converted by hydrogen peroxide to ammonia. Soil residues contain a base-exchange complex and, especially in acid soils, ammonia is strongly held by it. The high percentage of residual nitrogen is therefore no index of unconsumed organic matter.

McLean (*13*, *14*) in an attempt to develop the suggestion of G. W. Robinson and Jones (*20*) concerning the use of hydrogen peroxide for determining the "degree of humification" of organic matter, reached the conclusion that 3 per cent hydrogen peroxide may be so used but that the 6 per cent reagent is not suitable for the purpose. Incident to this investigation McLean has shown that even the most drastic treatment with 6 per cent and 12 per cent hydrogen peroxide is not sufficient to remove all of either the carbon or nitrogen content of the soil. He also showed that even 3 per cent hydrogen peroxide readily removes up to 85 per cent of the total carbon except in soils containing carbonates. He made no mention of interference by manganese dioxide. In these papers McLean also failed to consider the base-exchange ammonia of his soil residues and made no mention of the content of nitrogen of the hydrogen peroxide used. In consequence, the C:N ratios of his residues have in them an element of doubt.

EXPERIMENTAL DATA

The present study was undertaken to determine means of eliminating the difficulties brought about by (1) the presence of manganese dioxide in the soil and (2) the presence of carbonates, and to ascertain how nearly complete the removal of the organic matter can be made.

MANGANESE DIOXIDE

Manganese dioxide, if present in soils, reacts catalytically to decompose the hydrogen peroxide, and this reaction has been made the basis of a semiquantitative method of its estimation by W. O. Robinson (*23*). Also, in the paper previously cited, he reported that if the soils contain but a fraction of 1 per cent of manganese dioxide, its inhibitory effect on the destruction of organic matter could be eliminated by the use of oxalic acid.

For various reasons it seemed desirable to use, if possible, an acid weaker than oxalic, and the following data were obtained, using acetic acid. The soil employed was the Wabash silt loam surface soil which contains 0.11 per cent of manganese calculated as manganese oxide. The quantity of manganese in this soil does not interfere with the removal of the organic matter.

To 10-g samples of this soil were added varying quantities of precipitated manganese dioxide and of acetic acid, and the amount of carbon dioxide developed by treatment with 20 c c of hydrogen peroxide was measured. The results are given in Table 1. Blanks were run, using acetic acid and hydrogen peroxide, and but traces of CO_2 were evolved.

TABLE 1.—*Effect of manganese dioxide and acetic acid on the liberation of carbon dioxide from 10 g of Wabash silt loam treated with hydrogen peroxide*

Manganese dioxide added	Acetic acid added	Hydrogen peroxide (6 per cent) added	Carbon dioxide evolved	Manganese dioxide added	Acetic acid added	Hydrogen peroxide (6 per cent) added	Carbon dioxide evolved
Mg	*Mg*	*Cc*	*Mg*	*Mg*	*Mg*	*Cc*	*Mg*
0	0	20	105.8	10	10	20	112.7
10	0	20	55.3	50	20	20	10.5
50	0	20	17.5	50	20	40	74.1
100	0	20	4.0	50	20	60	174.2
0	10	20	112.2				

The action of the hydrogen peroxide results in part in solution and in part in conversion of the soil organic matter to carbon dioxide. In order to determine how completely the organic matter is removed the experiments reported in Table 2 were carried out.

TABLE 2.—*Effect of manganese dioxide and acetic acid on the removal of organic matter from 10 g of Wabash silt loam*

Manganese dioxide added	Acetic acid added	Hydrogen peroxide (6 per cent) added	Organic matter removed	Manganese dioxide added	Acetic acid added	Hydrogen peroxide (6 per cent) added	Organic matter removed
Mg	*Mg*	*Cc*	*Per cent*	*Mg*	*Mg*	*Cc*	*Per cent*
100	0	40	0.81	100	100	80	1.85
100	100	40	1.38	0	0	(2)	3.10
100	0	60	1.19	10	[1] 10	(2)	2.95
100	100	60	1.73	100	[1] 100	(2)	2.85
100	0	80	1.48	200	[1] 200	(2)	2.93

[1] A slight excess over the equivalent amount of acetic acid was used.
[2] An excess of hydrogen peroxide.

It will be seen from a study of Table 2 that with relatively small quantities of acetic acid the catalytic effect of the manganese dioxide is largely eliminated, and that if repeated treatments with hydrogen peroxide are used, the organic matter may be as nearly completely removed as when manganese is not present. It should also be observed that as the quantity of manganese dioxide increases, the quantity of hydrogen peroxide used also must be increased, and in cases where the amount of manganese dioxide is in excess of 2 per cent, the cost in hydrogen peroxide and in time becomes excessive.

Although the matter was not followed to a definite decision, there are indications that traces of manganese are an aid to the oxidation process. In one case, in which the attack of the hydrogen peroxide on the soil was slow and incomplete, the addition of a milligram or two of manganese dioxide enabled the reaction to proceed rapidly to completion. It seems probable that manganese dioxide is at least one of the catalytic agents in the reaction, and since manganese is practically an omnipresent component of soils with at least some of the dioxide probably present, all soils may for this reason accentuate the attack of hydrogen peroxide on organic matter.

CARBONATES

As previously noted, soils which contain appreciable quantities of carbonates do not suffer complete, or even nearly complete, removal of their organic matter, even after repeated treatment with hydrogen peroxide. If, however, these soils are first treated with hydrochloric acid, and the acid removed, the treatment with peroxide is as effective as in ordinary soils. It is known, of course, that acid treatment of itself removes some organic matter by solution, and it has been pointed out by Shorey and Martin (*29*) that, as a consequence of the presence of compounds of the uronic acid type in soils, heating the soil with even very dilute acid may produce an evolution of carbon dioxide. It follows, therefore, that the organic matter remaining in a soil after acid treatment is not all the organic material of the soil.

It seemed desirable, therefore, to determine the magnitude of these removals of organic matter and, if possible, to compensate for them in the use of the method.

In the course of the work it became clear, both from experimental evidence and on theoretical grounds, that all soils containing exchangeable calcium and organic matter may at times, and possibly always, contain carbonates, even though the quantity is so small that the usual qualitative test of effervescence with acid does not occur. Also, it would appear that moist soils must contain carbon dioxide and that even dry soils may contain occluded or adsorbed carbon dioxide. An added incentive to this study is that, as pointed out by Shorey and Martin (*29*), some of the considerations also come into question in the use of the combustion method.

In view of these considerations the Houston black clay of Texas was selected for careful examination. It not only contains a large quantity of carbonates and organic matter but is exceptionally resistant to attack by hydrogen peroxide.

Ten-gram samples of the soil were treated with sufficient hydrochloric acid and water so that after the solution of the carbonate the resultant solution would be approximately 5 per cent of hydrochloric acid. After effervescence had ceased, the solution was filtered off by use of a Pasteur-Chamberland filter and the residual soil was washed until free from chlorides. The solution was then neutralized with sodium hydroxide. It was evaporated under diminished pressure at a temperature of 80° C. In the evaporation train there was introduced an absorption bulb containing a solution of barium hydroxide so that all gases, except the water vapor, must pass through it. No carbon dioxide evolution occurred as a result of the decomposition of organic matter.

The resulting dry residue of calcium chloride and other inorganic material was then examined for the presence of organic matter. Two methods were employed. One was the ordinary dry-combustion method. In spite of the large quantity of chlorides and the consequent difficulties, the results obtained are believed to be accurate. The second method was the wet-combustion method, using a mixture of bichromate and sulphuric acid as an oxidizing agent.

In order to prevent absorption of any material other than carbon dioxide by the alkali solution used for estimation of the carbon, the absorption train consisted of a reflux condenser, a potassium iodide trap, a water trap, and a Liebig bulb of silver sulphate. The determination of the carbon dioxide was made by titration in the usual manner.

The soil used contained 10.82 per cent of calcium carbonate and 2.27 per cent of total organic carbon. The quantities of carbon found in the evaporated residue were 0.16 per cent by the dry-combustion method and 0.18 per cent by the wet method. Further work in this direction was not deemed essential in view of the data assembled by Rather (*17*) on the quantities of organic carbon dissolved by water and by acids from a series of 12 soils, including Houston black clay, in which he showed that the quantities so dissolved vary between 0 and 0.16 per cent of the dry soil. The average quantity found was 0.06 per cent. (P. 18.)

It will be seen from the subsequent discussion that, although determination of the dissolved organic carbon in this manner is too laborious and expensive for routine work, the error introduced, if it be negelected, is of a magnitude within the limits of the accuracy of the method in other respects. The above considerations are based on the use of 5 per cent hydrochloric acid, without heating, as a solvent for the carbonates. The reason for these limitations will appear from the data presented in the following section.

ACID EFFECTS ON NONCALCAREOUS SOILS

Shorey and Martin (*29, p. 4909*) have called attention to the fact that carbon dioxide is produced by treatment of soils with boiling 12 per cent hydrochloric acid. Indeed, boiling with 1 per cent hydrochloric acid produces an evolution of carbon dioxide, but "whether this carbon dioxide is derived from inorganic carbonate, occluded carbon dioxide, or from the first states of the decarboxylation of uronic acids, is under investigation." They ascribed this evolution to the presence in the soil of organic compounds of the

uronic acid type. Since the accurate determination of the carbon dioxide evolved by acid from soils is an essential step in the determination of organic matter from carbonate soils by any method, it became important to determine the magnitude of any error introduced by the action of acid on the organic matter. In the course of the work it became apparent that not all the CO_2 derived from the acid treatment came from the organic matter. There are two other possible sources—carbon dioxide "adsorbed" on the surface of the soil particles or held by soil moisture, or as acid carbonates; and carbon dioxide held as carbonates in quantities not evident by gas evolution on treatment with dilute acids. To deal with this problem a set of noncalcareous soils was selected, and the carbon-dioxide evolution studied under a variety of treatments. The apparatus used is shown in Figure 1.

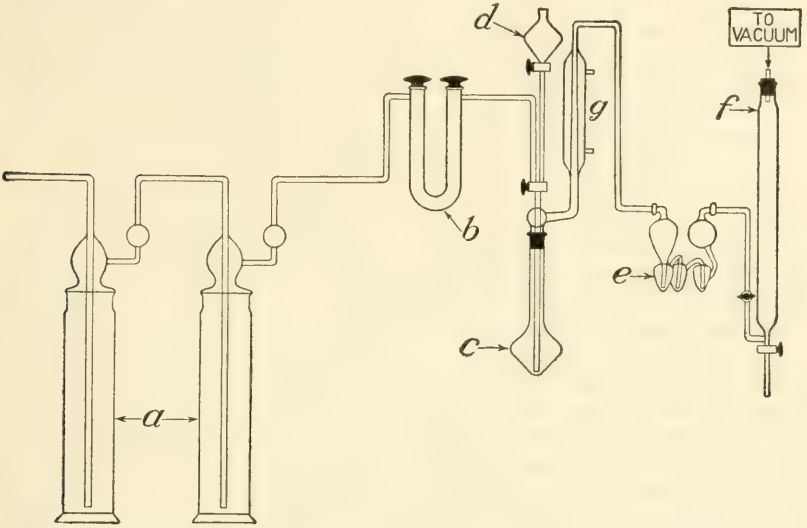

FIGURE 1.—Apparatus for determination of carbon dioxide: *a*, Gas-washing bottles containing KOH; *b*, soda-lime tube; *c*, gas-evolution flask; *d*, separatory funnel for introduction of acid; *e*, Liebig bulb containing silver sulphate and sulphuric acid; *f*, adsorption tower containing glass beads which are supported at the bottom by a platinum cone perforated by very small holes; *g*, condenser for use when contents of evolution flask are to be heated

This assemblage of apparatus presents no novelties so far as its single parts are concerned, but the purification train, evolution flask with automatic stirrer, reflux condenser, separator funnel, absorption train, and absorbing column, to the author's knowledge have not been assembled previously in any single apparatus. This device seems to be very satisfactory for accurate duplication of results of the order of magnitude encountered. When once assembled it is remarkably convenient for operation and requires relatively little manipulative skill. With it carbon-dioxide quantities as small as 0.2 mg may be duplicated accurately and, by altering the concentration of the alkali used in the absorbing tower, it may be used for even very large quantities of evolved carbon dioxide.

The samples were selected because they present a wide range of soil types, all of which are noncalcareous in the ordinary meaning of the term. Table 3 gives descriptive data on these and other soils used in this investigation.

TABLE 3.—*Soil types used in the investigation*

Soil No.	Soil type	Depth	Location
		Inches	
193	Carrington loam	0–12	Blackhawk County, Iowa.
181	Ontario loam	0–12	Rittsford, N. Y.
6797	Shelby silt loam	0–7	Bethany, Mo.
189	Wabash silt loam	0–15	Nemaha County, Nebr.
4440	Davidson loam	9–36	Guilford County, N. C.
7300	Blakely clay loam	0–3	Randolph County, Ga.
391	Hagerstown loam	0–8	Frederick, Md.
185	Cecil clay loam	0–9	Wilkes County, Ga.
199	Miami silty clay loam	0–10	Wells County, Ind.
512	Sharkey clay	0–4	Issaquena County, Miss.
5751	Houston black clay	.....	Dallas County, Tex.

The first four soil types were selected because they contain considerable quantities of organic matter that is readily removable, to a large degree, by hydrogen peroxide. The Davidson soil, by contrast, contains only a small quantity of organic matter and is not a surface soil. The Blakely soil contains 0.68 per cent of manganese calculated as manganous oxide. Hagerstown loam is a neutral soil.

The data included in Table 4, column 3, were obtained by treating 10 g of soil with 12 per cent hydrochloric acid and boiling for five hours. This is the treatment used by Shorey and Martin (*29*). It is tacitly assumed by them that all the carbon dioxide so liberated results from the decomposition of organic matter. Column 4 contains the data obtained by boiling the soils with 12 per cent hydrochloric acid for a period of 15 minutes. This series of determinations was made to ascertain the order of magnitude of the error introduced in the method of determination of carbon dioxide, as heretofore employed in the division of soil chemistry and physics (*24*). It will be observed that with the exception of the Blakely soil the quantity of CO_2 is exceedingly small, and since the laboratory method is ordinarily employed only when quantities of carbon dioxide are present sufficient to cause effervescence with HCl (1:1), the error introduced is quite negligible. This is not so unimportant relatively, however, with respect to the combustion method discussed later in this bulletin.

TABLE 4.—*Carbon dioxide evolution from certain noncalcareous soils of given pH values under diverse treatments*

Soil No.	Soil type	Percentage of carbon dioxide evolved from soil after treatment with—						pH
		12 per cent HCl, 5 hours boiling	12 per cent HCl, 15 minutes boiling	1 per cent HCl, 1 hour boiling	5 per cent HCl, aspirated 1 hour	H_2O only, aspirated 1 hour	5 per cent acid 1 hour after aspiration	
1	2	3	4	5	6	7	8	9
193	Carrington loam	0.293	0.057	0.038	0.009	0.006	0.003	5.0
181	Ontario loam	.215	.052	.078	.015	.003	.008	5.7
6797	Shelby silt loam	.203	.026	.054	.019	.008	.012	5.2
189	Wabash silt loam	.168	.035	.045	.010	.007	.003	5.6
4440	Davidson loam	.092	.052	.050	.023	.....	.....	.....
7300	Blakely clay loam	.567	.275	.402	{ .075 [1] / .015 }	.....	.....	.....
391	Hagerstown loam	.....	.....	.....	.....	.003	.045	7.0

[1] In presence of ferrous chloride.

In the Blakely soil, and in any soil containing oxidizing agents sufficiently active to oxidize hydrochloric acid, chlorine may be expected to oxidize organic matter with the production of carbon dioxide, although oxidation of organic compounds by chlorine may occur without carbonic acid evolution, e. g., galactose or glucose. In such instances it is desirable to use the modification described by Schollenberger (*25*). This modification suggests the use of ferrous chloride, which is preferentially oxidized by the liberated chlorine.[2] The Schollenberger method was not employed in the data given in columns 4 and 5, but was employed in the data given in column 6 for the Blakely soil.

Column 5 gives the results obtained by boiling 10-g samples with 1 per cent hydrochloric acid one hour. It will be noted that in some instances the quantity of carbon dioxide produced was in excess of that produced by boiling with 12 per cent HCl for 15 minutes. Undoubtedly if the boiling with 1 per cent acid were sufficiently long continued even this dilution of acid would effect extensive decomposition of compounds of the uronic acid type (*9*). In this case also the effect of manganese dioxide on the quantity of carbon dioxide is very marked in the Blakely soil.

In column 6 are given the data obtained by using 10 g of soil with 5 per cent hydrochloric acid and aspirating with purified air at the room temperature for one hour. The quantities of carbon dioxide obtained are notably less than are obtained by boiling with 1 per cent acid. In the Blakely soil the second value is that obtained by addition of ferrous chloride, and the difference indicates the oxidizing effect, under these conditions, of the manganese dioxide in this soil. A point of special interest in this series is that if the aspiration is continued for successive periods of one hour each, no measurable liberation of carbon dioxide occurs. This is in marked contrast with the series with boiling acids given in column 5, in which in all cases no end point was reached though the successive increments were of diminishing value.

The obvious interpretation of these facts is that the carbon dioxide evolved by the cold acid arises from carbonates present even in these soils, most of which are distinctly acid. This conclusion seems to be in harmony with the consideration that since all fertile soils contain bases and the organic matter present is, under moist conditions, producing carbon dioxide as a result of bacterial activity, there must, therefore, at all times be an unstable condition tending toward equilibrium between the basic content of the soil and the carbonic acid content of the soil solution. When the carbonic acid content

[2] An interesting observation was made in this connection. Cameron and Breazeale (*5*) comment on the observed fact that soil-containing chlorides, when treated with sulphuric acid and chromic acid, under certain conditions fail to produce chlorine evolution in sufficient quantity to affect the carbon dioxide determination by the wet-combustion method, and state that they have no explanation. The same observation was made in the treatment of the Blakely soil with hydrochloric acid, although manganese dioxide and hydrochloric acid must produce chlorine. The explanation is that the chlorine so formed reacts with water to produce hypochlorous acid which oxidizes organic matter to give carbon dioxide or decomposes to liberate free oxygen. The evidence that this occurs is found in the fact that no free chlorine can be detected in the neck of the flask below the condenser but is readily detected even by color, as well as by starch iodide paper, just above the surface of the liquid. Unless the oxidizing agent in the soil be considerable in amount, no free chlorine passes into the absorption train.

increases sufficiently the existence of bicarbonates becomes possible. On drying, these bicarbonates, so far as calcium, magnesium, and ferrous iron are concerned, will revert to carbonates and, in part, the carbon dioxide so liberated may be retained by the soil.

To determine the relative amounts of the carbon dioxide present as "adsorbed" gas, 10 of the soils were aspirated with distilled water which had been boiled and cooled in a closed vessel. The results of this series of determinations are given in column 7. It will be observed that the quantities so obtained are close to the limits of the accuracy of the method employed in the measurement. Nevertheless, the series as a whole indicates the order of magnitude of the quantities of carbon dioxide present, either as adsorbed gas or as bicarbonates. The samples were then treated with sufficient hydrochloric acid to make the acid concentration 5 per cent, and the aspiration continued for another hour. The results obtained are found in column 8. To this set was added a soil which had a normal pH of 7. The sharply increased difference between adsorbed CO_2 and that present as carbonate is striking and is considered as excellent confirmation of the general conclusion.

On the basis of the data represented by Table 4 it appears that an error of considerable magnitude is introduced into the determination of the carbonates present in calcareous soils if the boiling with hydrochloric acid (1:2) is long continued. This error is minimized when the period of heating is limited to 15 minutes. Soils, even when acid, may contain measurable quantities of carbonates: these quantities are of a negligible magnitude, except where the degree of base saturation approaches 100 per cent. Additional data on the carbon dioxide content of certain soil colloids by use of this method are given by Middleton, Slater, and Byers (*15*).

The difficulties produced by the presence of manganese dioxide and calcium carbonate in soils do not appear to be insuperable obstacles to the use of the hydrogen peroxide method. It remains to consider the question of the residual carbon content of the treated residues. For this purpose nine soils were used and the removal of the organic matter was made as complete as practicable by repeated treatment with 6 per cent hydrogen peroxide. The carbon content of the treated residues was determined by the combustion method. The results obtained are given in columns 3 and 4 of Table 5. It will be observed that the carbon content of the hydrogen peroxide residues varies between 0.15 per cent and 0.44 per cent of the whole soil and averages 0.25 per cent. This quantity corresponds to 16.4 per cent of the original carbon content of these soils. If the assumption is made that this residual carbon is from organic matter, to which can be ascribed the carbon content used as a conventional factor in the combustion method, the quantity of residual organic matter (column 5, Table 5) is considerable.[3]

[3] That this assumption is not valid arises from the fact shown by W. O. Robinson (*22*) that at least a portion of the residual carbon is not organic matter (p. 2) and by the further fact, shown later in this bulletin, that even with organic matter the conventional factor is inaccurate.

TABLE 5.—*Organic matter by the hydrogen peroxide method*

Soil No.	Soil type	Organic matter by hydrogen peroxide	Carbon in residue	Organic matter in soil residue (C×1.724)	Total organic matter in soil	Total organic carbon by combustion	Organic carbon removed by H_2O_2
1	2	3	4	5	6	7	8
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
199	Miami silty clay loam	2.16	0.22	0.38	2.54	1.51	85.6
193	Carrington loam	4.62	.28	.48	5.10	2.71	89.7
512	Sharkey clay	4.29	.44	.76	5.05	2.96	86.2
185	Cecil clay loam	.39	.11	.19	.58	.42	73.8
6797	Shelby silt loam	3.01	.31	.53	3.54	1.82	83.0
189	Wabash silt loam	2.78	.25	.43	3.21	1.87	86.6
181	Ontario loam	3.34	.24	.41	3.75	2.12	88.7
391	Hagerstown loam	1.23	.24	.41	1.64	.90	73.3
5751	Houston clay	3.10	.15	.26	[1] 3.65	2.27	85.5
	Average						83.6

[1] Includes organic matter in HCl filtrate.

In order to determine the degree of removal of the organic matter by the hydrogen peroxide, it seemed best to determine the total carbon by the dry-combustion method, column 7, and from this to calculate the percentage of organic carbon removed by the peroxide treatment. These values are given in column 8, Table 5, and vary between the limits of 73.3 and 89.7 per cent. The percentage of organic matter removed is obviously of the same order of magnitude and would be identical were the residual organic matter of the same composition as that removed.

In general, the conclusions arrived at by W. O. Robinson (*22*) are confirmed. It appears certain in cases where a large quantity of carbon remains unconsumed that it may consist of organic compounds of uncertain carbon content. The evidence of this is admittedly indirect but is considered convincing by the authors. The most important indications that such is the case are as follows:

In none of the residues of the soils examined could any particle of carbon be positively identified by microscopic examination. This alone is not convincing, but when coupled with the fact shown by Robinson (*22*) that powdered charcoallike particles separated from the soil are largely consumed by hydrogen peroxide, it would seem that submicroscopic particles ought to be attacked. It has also been pointed out by Shorey and Martin (*29*) that the residue contains nitrogen, and this fact has been confirmed by the authors even when the nitrogen present as exchange ammonium was taken into account. The following data on the examination of a Chester silt loam sample are submitted as an example:

	Per cent
Organic carbon in the original soil	1.78
Organic matter removed by H_2O_2	2.41
Carbon content of residue	.37
Nitrogen content of soil	.156
Nitrogen content of residue	.032
Nitrogen as exchangeable NH_3	.016
Residual organic nitrogen	.016

It will be noted that the C:N ratio is 11.4 in the original soil and 23.1 in the residue after peroxide treatment. The important deduction to be drawn from this confirmation of the work of Shorey and Martin (*29*) is that the residual material has a carbon-nitrogen ratio not unusual in soils and therefore indicates the presence of actual organic matter in the peroxide-treated residues. More detailed data need not be given because of the data to be found in the work submitted by Leighty and Shorey (*8*) and by McLean (*13*, *14*). The former showed in a study of alteration of the carbon-nitrogen ratio in a very large number of profiles, that the ratio decreases with depth in most instances, but the reverse situation also obtained in a few cases. This result indicates an alteration in the rate of destruction of nitrogenous and nonnitrogenous material under differing soil conditions. The results of McLean on the carbon-nitrogen ratio of peroxide-treated residues also show alteration from the ratio of the original soils. It does not appear that he measured the base-exchange nitrogen, and consequently the detailed figures obtained are not significant. They do show, however, that normal soil organic matter is probably present in these residues.

That some forms of organic matter are highly resistant to hydrogen peroxide when not in contact with soil is well known. It seemed desirable to secure a few such substances, known to be present in soil organic matter or organic matter likely to find its way into soils, and determine to what extent they yield to this treatment in the presence of soil. The soil employed was a sample of Chester loam and the samples in question were mixed with this soil in the ratio of 1 to 5.

The resulting data are given in Table 6.

TABLE 6.—*Organic materials and hydrogen peroxide in the presence of soil organic matter*

Substance	Loss by H_2O_2 alone	Loss by H_2O_2 and soil	Ash	Organic matter destroyed
	Per cent	*Per cent*	*Per cent*	*Per cent*
Lemon pectin	86.7	89.5	7.9	97.2
Peat from Lake Mattamuskeet	73.9	81.5	9.7	90.2
Apple cuticle	18.5	34.8	.5	35.0
Lignin	52.3	78.9	.7	79.4
Indigotin	0	91.8		91.8
Oleanolic acid	−.9	3.4	0	3.4

The lemon pectin is a material very rich in uronic acids. The peat used is very rich in alcohol-soluble material. The apple cuticle was furnished by C. E. Sando, of the Bureau of Chemistry and Soils, and is highly resistant to oxidation. The lignin is a sample of purified material furnished by Max Phillips, of the Bureau of Chemistry and Soils. The oleanic acid is a material extracted from grape skins by C. E. Sando and known to be highly resistant to oxidation.

Certain minor, but real, sources of error in the use of the hydrogen peroxide method arise as the result of reactions between the hydrogen peroxide and the inorganic portions of the soil. The more significant of these is that hydrogen peroxide is a weak acid itself and with

organic matter produces carbonic acid. Both these effect base-exchange reactions with the bases of the soil complex and whether they pass into solution or not have the effect of diminishing the apparent organic-matter loss by reason of the hydrolysis so produced. Directly or indirectly the reaction is as indicated by the following equation:

$$MX+H_2O \rightarrow MOH+HX$$

For each equivalent of base so removed there is added a molecule of water. When the soil residue is dried or the hydrogen peroxide extract ignited, the weight relation is as indicated or corresponds to half a molecule of water, depending on whether the hydroxide is converted to oxide in the process. It is clearly a task of considerable magnitude to determine in any one instance the exact effect of this type of reaction, and it does not seem worth while since each soil sample would have its own correction values. It is not difficult, however, to determine the existence of the source of error and obtain a general estimate of its magnitude. For this purpose 10-g samples of Shelby silt loam and of Carrington loam were treated with hydrogen peroxide until the organic matter was removed. At the same time duplicate samples of each were treated with the same volume of distilled water and subjected to the same procedure. The filtered solutions were evaporated to dryness and ignited. The ignited water residue amounted to 6.6 mg for the Shelby sample and 8.9 mg for the Carrington. The corresponding weights for the peroxide extracts were 33.6 and 43.3 mg.

Were the differences between the weights of these extracts due wholly to conversion of exchangeable calcium to calcium oxide, the error introduced would give too low values for the organic matter in these soils by about 0.1 per cent.

A less significant error is due to the fact that since hydrogen peroxide is an oxidizing agent, any oxidizable inorganic material in the soil will be oxidized to some extent, and to the degree that such oxidation occurs the added oxygen would make the organic matter values too low. It is not believed that this error is of moment in most soils, since almost the only oxidizable inorganic matter in soils is ferrous iron. It is probable that when such is present the oxidation primarily results in the base-exchange phenomenon discussed above. In any case the general effect of the hydrogen peroxide treatment is not greatly to intensify the color of the treated residues, even when high in iron.

In the light of all the data at present obtainable, it appears that the hydrogen peroxide method is not satisfactory as a means of determining the total organic matter of the soil. It can be a very useful means of comparing the readily oxidizable material in different soils and especially in comparing the quantities of organic material in different samples of the same soil. If it be supplemented by a combustion determination of the residue, the carbon content may be assumed to be normal organic material and multiplied by a conventional factor, or the assumption suggested by Robinson (*22*) may be used, and in either case a fairly close approximation to the real organic content be reached.

THE COMBUSTION METHOD

In the following discussion attention is not directed primarily to the means by which the quantity of carbon in a soil is determined. It may be said at once that so far as the authors can determine, both the wet and dry combustion methods, when carried out with suitable precautions, accurately estimate the quantity of carbon dioxide produced. A review of many of the available methods with critical comments was furnished by Springer (*31*) in 1928.

There seem to be three points which merit consideration in the present discussion. The first, and by far the most important, concerns the use of a factor to convert the carbon, or carbon dioxide content, into the organic matter of the soil. The second is the determination of the corrections to be applied when calcareous soils are studied, or, in the case of the wet-combustion method, when alkali soils are in question. The third concerns the residual material after dry combustion has been employed to determine the carbon content.

THE ORGANIC FACTOR

The use of the conventional factor, 1.724, to convert the carbon content of a soil to organic content, is open to serious criticism. From the literature it would seem that there is considerable uncertainty concerning the origin of this factor. There seems to be little doubt that it owes its extensive use to Van Bemmelen (*3*) who ascribes its origin to Wolff (*34*).

The earliest mention found of 58 per cent as the carbon content of humus, which carbon content is the basis of the conventional factor, is by Sprengel (*30*), who, in 1826, in a rather extensive paper, gave the composition of humus as 58 per cent carbon, 39.9 per cent oxygen, and 2.1 per cent hydrogen. He used the copper oxide combustion method but did not give any detailed data. This paper was given scant and unfavorable comment by Berzelius (*4, p. 288*) who, on other grounds, considered the work reported so inaccurate as to be untrustworthy. In the light of the data quoted by Dana (*6*) in 1858, in A Muck Manual for Farmers, as derived from Mulder, the result obtained by Sprengel for humus extracted by alkali was fairly accurate, considering the analytical methods available. Mulder's values are as follows:

Kind of soil	Percentage of carbon in humus
Fruit-orchard soil	58.49
Kitchen-garden soil	61.65
Field (mowing) soil	60.11
Oak-plantation soil	58.98

In 1864, Wolff (*34 p. 156*) made the following statement, although the analytical data on which it is based do not appear:

Um aus dem Kohlenstoffgehalt des Bodens die Menge der Humussubstanz wenigstens annähernd genau zu berechnen, nehme ich im Humus durchschnittlich 58 Proc. Kohlenstoff an; Man braucht also den Kohlenstoff nur mit 1.724 oder die gefundene Kohlensäure mit 0.471 zu multipliciren, um auf diese Weise den Gehalt des Bodens an wasserfreiem Humus zu finden.

This statement seems to be the basis for all the later use of these factors when combustion methods are employed for determining the organic content of soils.

Detmer (*7*), in 1871, found the humus of soil to have a carbon content of 59.79 per cent. Loges (*10*), in 1883, in a study of the wet and dry methods of combustion, used the Wolff factors freely to calculate the total "humus substance" of soils. In 1890 Van Bemmelen (*3*) made the following statement concerning the humus content: "Dieser ist erhalten durch Multiplikation des Kohlenstoffgehaltes mit den factor von Wolff: 1.724." This statement may be considered as establishing the general use of the factor.

That the organic matter of the soil may be widely different in carbon content from 58 per cent and that the factors 1.724 and 0.471 are, in consequence, unreliable, has been shown repeatedly. Indeed, numerous investigations have shown that even in the extracted soil humus, the mean values of the carbon content have been found to be more nearly 50 per cent than the 58 per cent assumed in the use of the above factors. Only a few of these will be cited.

Cameron and Breazeale (*5*), in 1904, showed that the humus extracted from 19 "typical" agricultural soils by 3 per cent ammonia contained percentages of carbon varying between the limits of 33.3 and 49.22 per cent and averaged 41.77 per cent. Curiously enough, they advised the continued use of the factor 1.724. They reached this conclusion, partly at least, on the basis of the following statement (*5*, *p. 44*):

> Furthermore this organic matter, not extracted by the ammonia, is made up largely of cellulose, or celluloselike substances in which the percentage of carbon approaches closely the figure given by Van Bemmelen.

Since the carbon content of cellulose is 44.44 per cent, this value in reality approaches much more closely their value for the extracted material than it does the value used as the basis of the factor which they erroneously attributed to Van Bemmelen.

In 1922, Read and Ridgell (*19*), using the method of Rather (*17*), to be later discussed, on a series of 37 soils of very diverse sources, found a variation of carbon content between the limits of 30.2 per cent and 56.27 per cent, with a mean value of 49.26 per cent, in the surface soils, and a variation between 13.33 per cent and 56.55 per cent, with a mean of 39.16 per cent for subsoils of the same series of soils. The mean for the whole series of soils for both surface soil and subsoil was 43.91 per cent. These results are in general harmony with those of Cameron and Brezeale (*5*). They are distinctly out of harmony with the results obtained by W. O. Robinson (*22*) who found, for the organic matter of the material removed by hydrogen peroxide, values ranging from 37.5 to 70.1 per cent, with a mean value of 54.8 per cent. On the assumption that the residues, after treatment, consisted wholly of carbon, he calculated the total organic matter to have a carbon content which ranged between 44.5 and 78.4 per cent, with a mean value of 58.6 per cent. It should be added that in the series of soils examined, the maximum values were shown by a soil known to contain free charcoal particles. Excepting this soil, the maxima were 61.9 and 66.5 per cent.

Lunt (*11*), in 1931, in a study of the carbon-organic ratio of forest soil humus, found for freshly fallen leaves a factor of 1.89; for partly decomposed leaves, 1.85; and for well-decomposed leaves, 1.80. In this study the loss on ignition was used as a basis of esti-

mation of total organic matter and, although this method is obviously faulty as applied to soil, it is not so seriously questionable when used on the materials studied.

A recent article by Waksman and Stevens (*32*) discusses the limitations of the hydrogen peroxide method and the use of chlorine dioxide in estimating the organic content, of certain types of material, which have a very high organic content, and finds them unsatisfactory as used. The authors state (*32, p. 114*):

> The most reliable method at present for determining quantitatively the soil organic matter is based upon the determination of organic carbon, which is multiplied by 1.724 to give a total soil organic matter.

They adduce no positive evidence from any source for this statement.

In view of the wide variance shown throughout the literature cited above, it seemed not to be essential to carry out detailed examinations for the purpose of again showing the divergence of values obtained by the different methods. However, the data given in Table 8, show that no close concordance exists between the hydrogen peroxide method and the combustion method when used on the same soils, even though "correction" be made for the residual carbon after hydrogen peroxide treatment. Incident to the use of the Rather method (see beyond) the values for the carbon content of the organic matter of these soils, which is not soluble in a mixture of hydrochloric and hydrofluoric acids, are available. (Table 8, column 8.) The range is from 46.8 per cent to 61.4 per cent.

It would appear from the accumulated data that however accurately carbon may be determined in a soil, the error introduced by the use of the conventional factor is very great. It is, therefore, futile to attempt to arrive at any factor, since existing data show that, as a matter of fact, the carbon content of soil organic matter is extremely variable. Some have endeavored to avoid the uncertainty introduced by the use of a factor by contenting themselves with the determination of the carbon and basing comparisons between soils on the quantities so found. Such procedure is analytically sound but not very satisfactory, since the quantity of the material represented by the same carbon content may be essentially different, and quantities of carbon may be quite different and yet represent like quantities of organic material. Even if reporting carbon content alone were satisfactory in general, there is one very important purpose that can not be so served. The combined water is a very important component of the soil, and its estimation depends at present on the difference between the ignition loss and the organic content. The carbon content serves in no way to obtain the water content, and, unfortunately, any error brought in by the use of the factor 1.724, or any other factor, makes a like error in the water component. This is so serious in the study of inorganic soil constitution as to make an accurate method of determination extremely desirable, entirely aside from its importance to the study of the organic matter itself.

CARBONATED SOILS

As was pointed out in the review of the hydrogen peroxide method, the accurate determination of the carbon dioxide content of a soil

involves the consideration of a number of factors. Thus, if the combustion method be employed on calcareous soils, any error in the estimation of carbon dioxide resulting from acid treatment is immediately reflected in the estimation of the organic matter; this is true whether the error be caused by the decomposition of organic matter or otherwise.

The data already presented show that, although the method of determining the carbon dioxide by boiling with 12 per cent HCl for a short period is not likely to introduce significant error into the estimation of the carbonates, it is likely to produce a relatively more important error in the calculated organic content, especially since it is uncertain whether a portion of the carbon dioxide so determined has its origin in organic matter. It also seems apparent that the quantity of carbon dioxide present in noncalcareous soils is sufficiently large, especially in soils which approach or pass neutrality, to warrant a carbon dioxide determination in every case where organic matter is to be determined.

The question of the retention of carbon dioxide derived from the combustion of organic matter appears to depend somewhat on the character of the soil. In the absence of actual alkali carbonates, there seems but little likelihood of appreciable quantities of potassium or sodium carbonates being formed by reaction between the carbon dioxide and exchange bases in the soil which escape decomposition at the furnace heat. As a matter of fact this residual carbon dioxide is small but real in the nonalkaline soils under examination. The results obtained are given in Table 7.

TABLE 7.—*Carbonates in residue after combustion*

Soil No.	Soil type	Percentage of CO_2 in residue	Soil No.	Soil type	Percentage of CO_2 in residue
193	Carrington loam	0.044	181	Ontario loam	0.016
6797	Shelby silt loam	.011	512	Sharkey clay	.022
199	Miami silty clay loam	.044	5751	Houston black clay	.000
185	Cecil clay loam	.051			

So far as the authors are aware, the presence of alkali carbonates in itself offers no difficulty to the use of the dry-combustion method, but the associated so-called alkali salts may at times offer manipulative difficulties, and the wet-combustion method is to be preferred.

The combustion method seems to be a very satisfactory means of estimating the carbon content of soils, assuming proper precautions are taken to insure accuracy of results and to avoid errors incident to the presence of carbonates. When we undertake to translate the carbon content into organic-matter content, the method is useless for any purpose other than a rough comparison. It is difficult to understand why its use should have been so long continued except for the belief that no more satisfactory method existed, and it is better to use a poor tool than to do no work. Certainly the relative quantities of organic matter in soils is an important question, and a satisfactory method is greatly to be desired.

LOSS ON IGNITION

The loss on ignition has long been used as a measure of the relative organic content of soils. (*2*) That the direct application of this method is accompanied by gross error is too well known to warrant a detailed review of the proofs of its inadequacy. The hydrated minerals of the mica and zeolite types and the "water of constitution" of the colloids and of clay minerals are included in the ignition loss. It is important to determine the water content of soils and colloids as well as to determine the organic matter itself. A very valuable aid to soil study would be secured if a method were available for distinguishing between the portions of the total ignition loss due to organic matter and to the dehydration of inorganic materials.

In 1917 there appeared a bulletin of the Arkansas Agricultural Experimental Station by Rather (*17*) in which the distinction just mentioned was attempted. Rather's method consists essentially in the removal of the hydrated mineral matter of soils by repeated treatment with a mixture of dilute hydrochloric and hydrofluoric acids and subsequent washing to remove these acids and their soluble salts. The residual organic matter is then determined by ignition. It is obvious that this method involves the removal of the organic matter which is soluble in water and in acids at the dilutions employed, or which is decomposed by treatment with acids. The extent to which such removal of organic matter before ignition occurs can be approximated by determining the total carbon before and after extraction with acids. In a series of determinations on 12 soils, Rather demonstrated that the loss of carbon by leaching was small, varying between 0.01 and 0.16 per cent with an average loss of 0.06 per cent. This paper was followed by Read (*18*) who applied the method of Rather to effect a simultaneous determination of organic matter and organic carbon, and in doing so developed a wide variation in the percentage content of carbon. This was, in turn, followed by a more extended paper by Read and Ridgell (*19*). They presented the results of a study of the Rather method with reference to the question of the validity of the conventional factor to which attention has already been drawn. (P. 15.) In the 1926 edition of Wiley's Principles and Practice of Agricultural Analysis (*33*) this method of examination was somewhat briefly discussed and was dismissed with the comment that "the method gives very satisfactory results but is quite chronokleptic." In view of the importance of the matter it seemed desirable to reexamine this method, despite its time-consuming character, and apply it, or a modification of it, to the same soils which were examined by the methods previously discussed.

EXPERIMENTAL DATA

In Rather's (*17*) detailed method soils are first leached with water and then treated repeatedly on the water bath with a 1 per cent solution, consisting of 0.5 per cent hydrochloric acid and 0.5 per cent hydrofluoric acid, until a constant ignition loss is obtained. The quantity of organic matter dissolved by the water may be determined separately. In view of the observations previously discussed in this bulletin, it seemed best to modify Rather's method in certain details.

In securing the data given in Table 8, the soils were treated with a mixture of 2.5 per cent hydrochloric acid and 2.5 per cent hydrofluoric acid in platinum dishes and allowed to stand overnight at room temperature, and, after filtration, this treatment was repeated. The soil residue was washed until free from chlorides. The filtrate was not directly examined for carbon content, but this was indirectly determined as later described. The soil residue was dried at 100° to 105° C. and then ignited in a muffle furnace and the ignition loss determined. This ignition loss represents the undissolved organic matter, if the hydrated inorganic matter has actually been wholly removed, and the residue contains no inorganic material which alters in weight during ignition.

A preliminary experiment to illustrate the degree of completeness of removal of hydrated inorganic material was carried out on a sample of the fraction of the B_2 horizon of Cecil clay loam, from Rutherford County, N. C., which does not pass a 300-mesh sieve. It consisted largely of mica, together with a small quantity of colloidal aggregates. It had an ignition loss of 9.4 per cent and a carbon content of 0.12 per cent. After one treatment with the mixture of acids the ignition loss was reduced to 2.32 per cent; after a second treatment the ignition loss was 0.27 per cent; and after a third treatment was 0.15 per cent. The calculated organic content was 0.20 per cent (0.12×1.724). This material should be considerably more difficult to free from hydrated minerals than ordinary soil. The authors are confident, therefore, that no material error in the application of this method was due to loss of "combined" water.

The results obtained on 11 soils are given in Table 8. The data in column 3 are the direct ignition losses obtained after the described treatment with the hydrochloric acid-hydrofluoric acid mixture, except in the case of Houston black clay. In this case, because of the high carbonate content, the soil was given a preliminary treatment with 5 per cent hydrochloric acid.

TABLE 8.—*Organic matter by the modified Rather method*

Soil No.	Soil type	Ignition loss	Organic carbon in filtrate	Carbon in filtrate ×1.724	Total organic matter by modified Rather method	Total organic matter assuming dissolved organic matter has same carbon content as given in Column 8	Carbon in organic matter of residue
1	2	3	4	5	6	7	8
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
193	Carrington loam	3.61	0.90	1.56	5.17	5.41	50.1
181	Ontario loam	2.87	.65	1.12	3.99	4.13	51.4
6797	Shelby silt loam	2.47	.53	.92	3.39	3.48	52.3
189	Wabash silt loam	2.24	.65	1.12	3.36	3.42	55.0
7300	Blakely clay loam	6.00	1.16	2.01	8.01	8.44	47.6
391	Hagerstown loam	1.47	.14	.23	1.70	1.74	52.0
185	Cecil clay loam	.65	.12	.20	.85	.91	46.8
199	Miami silty clay loam	1.91	.41	.70	2.61	2.67	53.9
512	Sharkey clay	3.79	.63	1.08	4.87	4.82	61.4
5751	Houston black clay	3.17	.57	.98	4.15	4.24	53.4
9356	Chester loam	3.09	.24	.42	3.51	3.57	49.9
	Average						52.16

In column 4 is given the carbon content of the organic matter dissolved by the acid treatment. These values were obtained by determining the total carbon content of the original samples by the dry-combustion method and subtracting from this quantity the carbon found in the acid-treated residue. It will be observed that the quantities so found are much higher than those obtained by Rather. (P. 18.) This is not alone due to the greater concentration of the acids employed, but also to the very greatly increased period of digestion in the cold acid. The values range from 0.12 to 1.16 per cent. The high value, 1.16 per cent, was obtained in the case of Blakely clay loam. This is a soil in which 0.68 per cent of manganese is present, calculated as manganous oxide. It is present chiefly as the dioxide, and were it all so present, it would correspond to a percentage content of 0.83. Without doubt the large solution loss in this case is due in part to the oxidation of organic matter by the products of reaction between the manganese dioxide and the acids. It is certain, however, that not all the dioxide present is decomposed by this process, since in the case of the Blakely sample the ignited residue was black, whereas in all the other samples the residues were nearly white or white. With manganese dioxide present in large amounts there occurs a source of error in the application of the Rather method not encountered in the combustion method. When manganese dioxide is treated with a mixture of the acids, even of the strength employed by the authors, it is attacked to but a slight degree. When the insoluble residue is ignited it is converted to the manganous manganic form Mn_3O_4, and the loss of oxygen from this source (12.2 per cent of the weight of MnO_2), if not compensated, is counted as organic matter. In ordinary soils the error introduced in this manner is very small, and even in the case of Blakely clay loam would be at the greatest but 0.1 per cent.

In column 5 of Table 8 are given the values obtained for the organic matter present in the acid filtrates calculated on the assumption that the conventional factor, 1.724, times the carbon content, is valid. Even if this be not true, it is obvious that less error is introduced by using the factor on a part of the carbon content than when it is applied to the whole.

In column 6 of Table 8 are given the values of the total organic matter in the soils obtained by adding the values in columns 3 and 5. In column 8 is given the percentage content of carbon in the undissolved organic matter after treatment with the acid mixture. It will be observed that these values range between 46.8 and 61.4 per cent, with a mean value of 52.16 per cent. It appears that, if we were only certain that the dissolved organic matter had the same carbon content as that not dissolved, we would obtain a very accurate estimate of the organic content of the soil by multiplying the carbon content by the factor corresponding to its percentage value. It is not probable that this is permissible, since the very fact that it is soluble differentiates it from that which is not dissolved. However, since it has been repeatedly shown that the carbon content of the organic matter of soils is variable and that, in whatever fraction isolated, the mean value is less than 58 per cent (as in the soils under discussion), a lesser error is introduced when the total organic matter is

calculated as indicated above than when the calculation is made as in column 6.

In column 7 are given the organic-matter contents of the soils on the assumption that the organic matter dissolved has the same carbon content as that not dissolved. It will be observed that the differences between the quantities given in columns 6 and 7 are in some cases very slight and in others quite appreciable. It is recognized that neither column 6 nor column 7 shows accurate values, but that the values in column 7 are probably somewhat closer to the real organic content of these soils.

COMPARISON OF THE METHODS

In order to facilitate comparison between the three methods under discussion the final values for each method on each soil have been brought together in Table 9.

TABLE 9.—*Comparison of organic matter determinations by the three methods studied*

Soil No.	Soil type	Organic matter by H_2O_2 method (from Table 5)	Organic matter by combustion method (C×1.724)	Organic matter by modified Rather method (C in filtrate× factor from Table 8, column 8)
1	2	3	4	5
		Per cent	*Per cent*	*Per cent*
193	Carrington loam	5.10	4.68	5.41
181	Ontario loam	3.75	3.66	4.13
6796	Shelby silt loam	3.54	3.14	3.48
189	Wabash silt loam	3.21	3.22	3.42
7300	Blakely clay loam	6.76	6.92	8.44
391	Hagerstown loam	1.64	1.55	1.74
185	Cecil clay loam	.58	.73	.91
199	Miami silty clay loam	2.54	2.47	2.67
512	Sharkey clay	5.05	5.10	4.82
5751	Houston black clay	3.62	3.91	4.24
9356	Chester loam	3.05	3.07	3.57

It will be observed that the organic matter content of these soils, as shown by the hydrogen peroxide method, is less than that shown by the modified Rather method in all the soils save Shelby silt loam and Sharkey clay. The difference in general between the values in column 3 and column 4 is small, and the quantities shown are essentially identical when the known sources of error of both methods are taken into consideration.

It appears that, if the precautions outlined in the preceding pages be used, the hydrogen peroxide method and the dry-combustion method are of equal validity, and, since both are apparently inaccurate, it is immaterial which method is employed for the purpose of estimating organic matter in soils, provided the same care is employed in each. Since the dry-combustion method is much more readily carried out and involves but one combustion, whereas the peroxide method requires in addition the careful technic of the hydrogen peroxide treatment, it follows that in general the dry-combustion method is to be preferred. It also seems to be true that where the object

sought is the relative amount of organic matter in various samples of the same or similar soils, the hydrogen peroxide method may be preferred when the combustion of the residues is omitted. It may be assumed that, since the hydrogen peroxide effects the oxidation of the more readily oxidizable matter, the relative amounts so shown are more truly an index of the organic matter available for bacterial consumption than are the relative amounts of total carbon multiplied by any factor. Although this assumption may be correct, proof of its validity is lacking. The need of a method for such distinction has been pointed out by Shorey (*27*).

It may be observed that in the combustion method the results may be either above or below the actual organic content, whereas in the hydrogen peroxide methods the results should invariably be low.

When we turn to the comparison of the dry-combustion method with the modified Rather method (Table 8, columns 4 and 5) it is found that the latter, in general, gives higher results for the organic-matter content. The single exception is in the case of Sharkey clay, and this difference is chiefly due to the high carbon content of at least the organic matter not dissolved by the acid treatment. (Table 8, column 8.) Similarly, the larger values in column 5, Table 9, as compared with column 4, are to be ascribed in part to the same procedure, using the larger factor required by the carbon percentages given in column 8 of Table 8. Nevertheless, even the smaller values obtained by applying the conventional factor to the acid-soluble organic matter still leaves (Table 8, column 6) them larger than those obtained by the dry-combustion method. The widest divergence is found in the case of Blakely clay loam, where the margin is 1.52 per cent. As already mentioned (p. 20) the presence of the manganese dioxide in this soil introduces a small source of error into the modified Rather method but operates to bring about values which are too low. It follows then that if the percentage carbon content given in column 8, Table 8, actually represents the carbon content of the total organic matter of the soils in question, then the high values of column 5, Table 9, are more nearly a quantitative measure of the true organic matter of the soil than are the quantities obtained by either the hydrogen-peroxide or the dry-combustion method, using the conventional conversion factor. That the percentage carbon content of the organic matter in these soils is variable between wide limits is abundantly supported by the experimental data as well as by the data presented in the references discussed. (P. 14.) The uncertainty regarding the carbon content of the acid-soluble organic matter is the most important element of doubt in the application of the Rather principle. That it offers the most satisfactory method at present available for the determination of the true organic content is believed to be shown. That the modified Rather method, as used by the authors, is time-consuming is undeniable. It requires two combustion operations, whereas the dry-combustion method requires but one, and, in addition, requires the time delay involved in successive treatments with the mixed acids and the subsequent washing and drying of the residues. The use of hydrofluoric acid involves the use of platinum vessels in considerable numbers, if many operations are to be carried forward at the same time. It is not to be expected, therefore, that the method will be employed for routine comparative purposes. It is

believed that this method, or an improvement, should be used when results of the highest possible accuracy are required.

The study of the problem of soil organic matter involved in the preparation of this bulletin lends emphasis to the contention of Waksman and Stevens (*32*) and of Shorey (*28*) that the organic matter of soils is not adequately differentiated when its quantity is determined accurately, even were that possible. That soil organic matter varying as widely in carbon content as the available data indicates should be of widely varying agricultural significance is beyond question. That the method of differentiation suggested by Waksman and the frankly qualitative method of Shorey are adequate for the purpose is more than doubtful. That better methods for the study of organic matter are urgently needed is obvious.

SUMMARY

A study of the organic-matter content of a group of soils by the hydrogen peroxide method, the dry-combustion method, and the modified Rather method is presented, together with a discussion of the defects of each method.

The conclusion is reached that none of these methods gives a satisfactorily accurate means of estimating the organic matter in soils. The attempt is made to show that the modified Rather method comes nearest to the objective sought, but that it is too slow and expensive for ordinary routine examinations. The fact that the dry-combustion method is based on a fundamentally inaccurate conversion factor does not invalidate its use for accurate determination of carbon content is pointed out.

The need for careful consideration of the carbonate content of soils as a part of the procedure in determining the carbon content of soils is emphasized and an improved procedure is suggested.

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PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS

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CONTENTS

	Page
Introduction	1
Outline of investigation	2
Experimental methods	3
Description of soil samples	3
Houston series	3
Kirvin series	4
Vernon series	4
Shelby series	5
Colby series	6
Cecil series	6
Palouse series	8
Marshall series	8
Composition and properties of the profile samples	9
Physical properties	9
Chemical composition of the soils	19
Chemical composition of the colloids	23
Properties of composite plot samples	34
Run-off and erosion data	43
General remarks	48
Summary	48
Literature cited	49

INTRODUCTION

Soil erosion is a problem which has confronted agriculturists as long as land has been cultivated. When fertile virgin soil is plentiful, little attention is paid to erosion, but when tillable land becomes scarce, soil preservation becomes economically necessary. The extension of eroded areas within the United States has only recently caused a serious scientific study of this problem of national soil conservation. The first attempt to determine the quantity of run-off and erosion from a limited area of soil was carried out in 1915 by the Forest Service in the Manti National Forest, Utah. (*25*).[1] Since that time erosion stations have been established by the Missouri Agricultural Experiment Station at Columbia, Mo. (*8*), the Texas Agricultural Experiment Station at Spur, Tex. (*4*), the Forest Service at San Bernardino, Calif. (*12*), and the Bureau of Agricultural Engineering at Raleigh, N. C.[2] In general, the purpose of establishing these stations has been to demonstrate and evaluate the enormous damage that is done to the soil by soil erosion. The pioneer work of these stations furnishes a meritorious introduction to the

[1] Italic numbers in parentheses refer to Literature Cited, p. 49.

[2] BARTEL, F. O. PROGRESS REPORT ON SOIL EROSION AND RUN-OFF EXPERIMENTS AT NORTH CAROLINA EXPERIMENT STATION FARM. U. S. Dept. Agr., Bur. Pub. Roads, Div. Agr. Engin. [Mimeographed.]

more extended study which is now being carried on by the Department of Agriculture and cooperating agencies.

The first step in this extended study was a reconnaissance survey made during 1928–29 for the purpose of locating and outlining the boundaries of the severely eroded areas in the United States. Eighteen districts were recognized in which soil erosion has become a serious menace.

When the attention of the Seventieth Congress was called to the national scope of the problem, an appropriation was made and authorization was given for the establishment of erosion-prevention and moisture-conservation stations in these areas. The first station established under this authorization was at Guthrie, Okla. This station has been in operation since July 1, 1929. Other stations have been established at Temple, Tex.; Statesville, N. C.; Hays, Kans.; Tyler, Tex.; Bethany, Mo.; Pullman, Wash.; and Clarinda, Iowa. A program of research is being carried out by the Bureau of Chemistry and Soils, in cooperation with the Forest Service and the Bureau of Agricultural Engineering, which anticipates the establishment of other stations as rapidly as sites and funds are made available.

Previous studies of erosion have been made by this bureau. In a bulletin published in 1911, McGee (*13*) described the damage caused by soil erosion and discussed means of control. In 1913 a paper by Davis (*5*) called attention to the economic waste of soil erosion. In 1915 Davis (*6*) made a survey showing the effects of erosion in the Southern States. A circular by Bennett and Chapline (*1*), published in 1928, served to focus attention on the problem, and, together with the work of the various erosion experiment stations noted above, stimulated interest in a more intensive study of erosion. In 1930, Middleton (*17*) published the results of a study on certain erosive and nonerosive soils and in this connection developed a measure of erosivity which at least has excellent qualitative significance. In 1931 there appeared a bulletin by Slater and Byers (*26*) in which a study was made of the composition of soils with respect to their percolation rate.

In connection with the establishment of erosion stations, this bureau plans to do extensive laboratory work on the soils, run-off, and eroded material. This publication is a report of the studies so far made of the soils on which erosion stations have been established.

OUTLINE OF INVESTIGATION

This bulletin includes the chemical and physical determinations which have been made on the soils of the erosion experiment stations established by this bureau and shows certain correlations between laboratory data and the available plot data. Large profile samples were obtained from each station which are representative of the soil on which the experimental plots are laid out. A small subsample of each of these was taken for the present study, and the remainder placed in storage so that at any future time a sample of the original material will be available. These subsamples were subjected to complete chemical and physical examination, including extraction and chemical analysis of the colloid.

At each station, plot samples were obtained in addition to the profile samples mentioned. These samples represent each horizon or layer of each plot. A standardized method of sampling was used which makes each sample a composite for the horizon it represents. The samples were subjected to physical examination only.

EXPERIMENTAL METHODS

The mechanical analyses were made by the method outlined by Olmstead and others (*18*). The colloid by water-vapor adsorption was determined by the method of Robinson (*21*). The moisture equivalent was determined by the method of Briggs and McLane (*2*). The suspension percentage and the dispersion and erosion ratios were determined by the methods outlined by Middleton (*17*). Percolation ratios were computed by the formula of Slater and Byers (*26*). Colloids were extracted by the methods outlined by Holmes and Edgington (*10*). Chemical analyses of the soils and colloids followed the procedure of Robinson (*23*). The pH determinations were made electrometrically, by means of the hydrogen electrode.

DESCRIPTION OF SOIL SAMPLES

The soils from the first eight severely eroded districts in which erosion stations have been established are representative of widely separated areas and great variation in climatic conditions. They are however, all located in regions of agricultural importance. The following descriptions include a general description of each soil series, taken from the files of the division of soil survey of this bureau, together with specific descriptions of the several samples of the types obtained from the erosion stations.

HOUSTON SERIES

The Houston series is developed in the calcareous prairie regions of Alabama, Mississippi, and Texas. The soils are derived from the weathering of calcareous clays, chalk beds (Selma chalk), and soft limestones. The surface ranges from almost level to undulating or gently rolling. Natural surface drainage is good, but internal drainage is retarded by the heavy character of the upper subsoil. The soils are characterized by the high content of lime in the subsoils and by the presence of calcareous material in most places within a depth of 3 feet.

In Alabama and Mississippi, soils of the Houston series have grayish-brown, rust-brown, or almost black heavy clay surface soils to a depth of about 6 or 8 inches. The subsoils to a depth ranging from 18 to 24 inches are brownish-yellow or drab heavy plastic clay which grades into greenish-yellow plastic clay, streaked or mottled with whitish soft lime nodules. Anywhere between a depth of 30 and 40 inches a white or light-yellow soft limestone or Selma chalk is present. The surface soil and upper subsoil are heavy plastic clays when wet, but they crack and become hard on drying. In cultivated fields the surface 2 or 3 inches crumbles down to a fine-granular structure. The Houston soils are adapted to the production of alfalfa, Melilotus, and other forage crops, including Johnson grass

and Bermuda grass. Cotton, formerly grown on these soils in Alabama and Mississippi, has been discontinued largely on account of the boll weevil. Corn does fairly well.

The Houston series in the Texas area differs from that in the Alabama-Mississippi area in that the soils are derived from Austin chalk and Taylor marl rather than from Selma chalk. The resultant differences in the soils derived from these formations, however, are so slight that the description of the soil survey for the Alabama-Mississippi area may be taken as descriptive of the Texas area as well. The Houston are regarded as among the most productive soils in the Texas area. The samples of Houston black clay used in this investigation were collected by G. W. Musgrave in January, 1930, at the erosion station 2 miles south of Temple, Tex. These samples contain more lime in the surface soil than is implied in the series description. The samples were described as follows:

(1) From 0 to 3 inches, black clay which is very plastic and sticky when wet but crumbles readily and is easily tilled when dry; (2) from 14 to 20 inches, grayish-black clay; (3) from 24 to 36 inches, gray clay; and (4) from 36 to 50 inches, yellowish-gray clay. The lighter-colored lower layers are more readily tilled when wet. The soil profile when saturated readily seals itself to penetration of surface waters.

KIRVIN SERIES

The Kirvin series is developed in the coastal-plain region, and the soils occur in close association with the Susquehanna soils. They differ from the Susquehanna in having reddish-brown or brown surface soils, a red upper subsoil, and a red or light-red, mottled with yellow, lower subsoil. The subsoils are stiff, rather compact but brittle clays as contrasted to the plastic, sticky subsoils of the Susquehanna. These soils are derived from beds of heavy clays or heavy sandy clays. Scattered over the surface in many places are large quantities of reddish-brown iron concretions or fragments. These soils occupy ridges, hillocks, and slopes, and they are naturally well drained. The Kirvin soils are somewhat more productive than the Susquehanna and are used mainly for growing cotton, corn, and forage crops.

The samples of Kirvin fine sandy loam were collected in July, 1930, by B. H. Hendrickson at the erosion station 9 miles northwest of Tyler, Tex. This area is strongly marked by deep gully erosion. The samples were described by Mr. Hendrickson as follows:

(1) From 0 to 12 inches, grayish-red loamy fine sand, including a thin organic surface layer; (2) from 12 to 24 inches, brick-red clay; (3) from 24 to 51 inches, brick-red clay mottled with gray; (4) from 51 to 63 inches, brick-red and light bluish-gray mottled very fine sandy clay with a seam of dark iron sandstone at a depth of 63 inches; and (5) from 63 to 75 inches, mainly yellow compacted fine sand.

VERNON SERIES

The soils of the Vernon series are Indian red or reddish brown. The upper subsoil is essentially like the surface soil of the Indian-red members, the color persisting to a depth ranging from 18 to 30 inches. The lower subsoil is yellowish red or Indian red and is

highly calcareous. The subsoil, except in the heaviest members, is somewhat heavier than the surface soil, but there has not been much translocation of clay into the subsoil and no formation of a definite clay pan. The soils are developed from the "Red Beds" of the Western States. In places where the soil, through erosion, consists essentially of the disintegrated parent rock, the calcareous subsoil may not have been developed.

The samples of Vernon fine sandy loam were collected by S. W. Phillips in June, 1930, at the erosion station located 4 miles south of Guthrie, Okla. The area is marked by severe gully erosion. The samples do not show the zone of lime accumulation which is mentioned in the series description. They are described by Mr. Phillips as follows:

(1) From 0 to 3 inches, dark-brown fine sandy loam containing some organic matter; (2) from 3 to 10 inches, red fine sandy loam; (3) from 10 to 27 inches, compact red slightly sticky sandy clay; (4) from 27 to 58 inches, gritty heavy tough clay, with sandy clay in streaks or layers, showing some evidence of the alternating shales and sandstone which comprise the parent rock. The predominant color is red, with some gray and pale-yellow layers of friable clay at a depth of about 50 inches. Some fragments of soft sandstone and shale are present in this layer.

SHELBY SERIES

The Shelby soils are dark-brown or almost black in their surface soils, and most of them are shallow. The subsoils are composed of yellow, reddish-brown, or brown sticky sandy clay, much of which contains coarse sand and gravel. Lime concretions and streaks of calcareous material occur in many places in the lower subsoil. As a rule, the subsoil becomes more clayey and compact and the percentage of clay increases with depth. The Shelby soils are derived from the sandy Kansan drift. The topography in most places is gently rolling to sharply rolling, as the soils occur on slopes where the sandy drift is exposed. Soils of this series differ from the Lindley soils only in the darker color of the surface soil.

The samples of Shelby silt loam were collected by R. E. Uhland in August, 1930, at the erosion station 6 miles west of Bethany, Mo. This area is subject to both sheet and gully erosion. There is but little waste land in the area as yet, although damage is serious and promises to become more serious with further cultivation. The samples were described by Mr. Uhland as follows:

(1) From 0 to 7 inches, a very dark brown surface soil; (2) from 8 to 12 inches, a drab-brown subsurface soil, containing some mottling; (3) from 12 to 20 inches, yellowish-brown heavy very sticky plastic clay; (4) from 20 to 24 inches, lighter-brown material than in layer 3, much less plastic, with a few small lime concretions (a transitional zone); (5) from 24 to 48 inches, a chalky layer containing many lime concretions (some of which, occurring at a depth of about 4 feet, are extremely large), many gravel of different sizes, and an occasional sand pocket; and (6) from 60 to 84 inches, rust-brown joint clay which breaks readily into cubes ranging from 1 to 1½ inches in diameter. The material caves very badly. Very few lime concretions occur at this depth.

COLBY SERIES

The surface soils of the Colby series are dark gray or dark brownish gray. The upper subsoil is of similar or slightly lighter color, of heavier texture, of compact structure, and ranges from 2 to 8 inches in thickness. The deeper subsoil is a light-brown or yellowish-brown silt loam of mealy consistence and friable character. The members of this series are composed of loessial deposits which have been in their present position for a comparatively long period. The surface portion, comprising the surface soil and upper subsoil material, has been considerably weathered. The topography ranges from nearly level to sharply rolling. These soils are well drained and are adapted to general farm crops under favorable climatic conditions.

The samples of Colby silty clay loam from the erosion station on the Fort Hayes Branch Station, State Agricultural Experiment Station, located 1 mile south of Hays, Kans., were collected by R. H. Davis in July, 1930. This soil is a true chernozem. Erosion is generally of the sheet type. The low rainfall of the area makes this station important not only from the standpoint of erosion but also from that of moisture conservation. The samples were described by Mr. Davis as follows:

(1) From 0 to 10 inches, brown or dark grayish-brown heavy silt loam or silty clay loam. The material of this horizon, especially at the lower depth, is mixed or splotched with more yellowish-brown material which has been brought up from below, probably by deep tillage. It is of fine-granular structure. Although only a few lime concretions are in evidence, the soil will effervesce freely with hydrochloric acid. According to the soil and erosion survey, from 3 to 6 inches of the original surface soil of this particular soil has been lost by erosion since the area has been in cultivation. (2) From 10 to 20 inches, light-brown or yellowish-brown silty clay loam of granular structure, the granules being larger than in the layer above. The insides of the granules are lighter in color than the outsides. Lime concretions occur in this layer. There are, however, wide local variations in the depth at which the lime accumulations occur, and within a few feet the depth may vary from 15 to 30 inches. The layers or veins of lime may be either on a horizontal, an inclined, or, in a few places, on a vertical plane. (3) From 20 to 33 inches, yellowish-brown silty clay loam containing a large number of lime concretions. The material tends to approach a columnar structure, and blocks break and crush easily. (4) From 33 to 47 inches, brownish-yellow or buff-colored silty clay loam which is high in lime and similar in structure to the horizon above. (5) From 47 to 60 inches, material of similar color and structure as the above layer, but parts or splotches of this layer appear to be of finer texture. Lime concretions are less abundant. (6) From 60 to 72 inches, buff-colored material which is of slightly coarser texture than the layer above, being of a rather silty character. Some fine sand is found in many places at this depth. Lime is present but not in abundance as in the above horizon.

CECIL SERIES

The Cecil series is the most widely distributed and the most extensive series of soils in the southern piedmont plateau. The soils

of this series are derived from granites, gneisses, and locally from schist. They occupy almost level to smooth and undulating broad interstream areas and gently rolling to rolling hilly and steep areas bordering the larger stream valleys. Excellent natural drainage exists everywhere, and it is even excessive on the slopes and hillsides, thus causing destructive washing and erosion. Two kinds of surface soils are found in soils of the Cecil series—soils which have a normally developed profile and include the sandy loams and loams and soils which have a mutilated profile, that is, one from which the original surface material has been removed, thus giving a B–C soil. The red members of this series belong to the latter class. A profile description of Cecil sandy loam in a virgin area is as follows:

A_1, 0 to 2 inches, dark-gray or brown sandy loam carrying a noticeable amount of organic matter. A_2, 2 to 8 inches, pale-yellow or brownish-yellow light sandy loam, containing practically no organic matter and leached of soluble minerals. A_3, 8 to 11 inches, reddish-yellow or yellowish-red heavy sandy loam grading into friable sandy clay. This is the gradational layer between the light-textured and light-colored sandy material and the typical red clay of the B horizon. B_1, 11 to 42 inches, bright-red or deep-red, stiff but brittle clay, which is sticky and slick when wet and hard when dry. The clay breaks into irregular-shaped lumps having no definite breakage or cleavage lines, but along the breakage lines the surfaces are slick. The large lumps can be crushed into smaller lumps and soil aggregates and finally into a granular angular mass. The color is uniform, but a cut surface is yellowish red. B_2, 42 to 60 inches, light-red friable and crumbly clay, which is slightly mottled with yellow in the lower part. It contains more mica and is much more friable than the clay of the B_1 horizon. C, 60+ inches, mottled light-red, yellow, and gray soft disintegrated rock, the parent material, which varies greatly in color from place to place, as it may be light red and yellow in one place and light gray, whitish, and yellowish only a few feet distant.

The B horizon varies greatly in thickness and in many places extends to a depth of several feet, particularly in some of the clay loam areas. A few mica scales are noticeable throughout the profile but are more abundant immediately below the parent material, and sharp angular quartz sand and veins of quartz rock are characteristic of the subsoil.

The samples of Cecil sandy clay loam from the erosion station located 10 miles west of Statesville, N. C., were collected in October, 1930, by J. W. Snyder. This is the only erosion station located on a lateritic soil. Such soils are not usually erosive, but the sandy character of the surface soil makes it erode readily when not protected by a vegetative cover. The area has suffered because of the prevailing type of agriculture which is chiefly the growing of corn and cotton. The samples are described by Mr. Snyder as follows:

(1) From 0 to 6 inches, the A horizon of light-brown sandy loam containing very little organic matter but more than either horizons B_1 or B_2. The surface soil in most places is friable and very easily worked unless it is eroded so that only a few inches of surface soil remain. (2) From 6 to 32 inches, the B_1 horizon of red clay loam which is very uniform and compact. (3) From 32 to 60 inches, the

B_2 horizon of red clay loam with brown mottlings. This material is very compact when exposed and has a tendency to crack.

PALOUSE SERIES

The surface soils of the Palouse series are dark, dull brown, or black, the brown tint being most pronounced under dry field conditions when the soil is viewed from certain angles. When wet, the surface soils are nearly black. The organic-matter content is high. The upper subsoils are brown or light brown and are of similar or heavier texture and more compact structure than the surface soils. The upper subsoil rests on a deeper subsoil of yellowish-brown color and of silty or silty clay texture, which is underlain by a tawny-yellow substratum of unstratified, homogeneous, loessial or wind-borne deposits. The parent material is derived from an undetermined wide range of rocks, and the soils are noncalcareous except in the deeper substratum. The topography is rolling or undulating, and the area covered is treeless. Drainage is well developed.

The samples of Palouse silt loam from the erosion station located 3 miles northwest of Pullman, Wash., were collected by W. A. Rockie in June, 1931. This area is characterized by steep slopes and light rainfall. Erosion is of the sheet type. The samples are described as follows:

(1) From 0 to 20 inches, dark-brown silt loam or silty clay loam containing much organic matter; (2) from 20 to 30 inches, yellowish-brown or brown silty clay; (3) from 33 to 62 inches, yellowish-brown or brown silty clay; (4) from 62 to 75 inches, yellowish-brown or brown silty clay loam; and (5) from 75 to 84 inches, yellowish-brown or brown silt loam or silty clay loam.

MARSHALL SERIES

The surface soils of the Marshall series are dark brown or black, and the subsoils are light brown or yellow. The texture of the subsoil is silty and little, if any, heavier than the surface soil. The structure is loose and friable. Both surface soil and subsoil are calcareous, the subsoil effervescing with acid. The topography ranges from gently to sharply rolling. The Marshall soils are derived from loess in which weathering has not reached an advanced stage, mainly from the newer loess along Missouri River. Corn is the principal crop, with grasses and alfalfa ranking next in importance.

The samples of Marshall silt loam were collected by G. W. Musgrave at the erosion station located 9 miles west of Clarinda, Iowa, in August, 1931. This area is marked by both sheet and gully erosion. The samples differ from the series description in that they contain no calcium carbonate. They are described by Mr. Musgrave as follows:

(1) From 0 to 13 inches, dark-brown silt loam which becomes plastic and cohesive when wet but has good natural drainage, and when dry is readily tilled; (2) from 13 to 24 inches, light-brown silt loam; (3) from 24 to 45 inches, material showing occasional grains of sand and slight evidence of drift; and (4) from 45 to 71 inches, rather gritty yellow silt loam (glacial drift).

COMPOSITION AND PROPERTIES OF THE PROFILE SAMPLES

PHYSICAL PROPERTIES

The mechanical analyses and other physical data, including also the hydrogen-ion concentration, of the samples described, are presented in Table 1.

The mechanical analyses are of value in determining the texture of the soils. Since the pipette method was employed in making the determinations, the textural classification does not correspond to that given in Circular 419 (7). The terminology employed is that used for these soils by the soil survey. The mechanical analyses also show the colloid content as defined by the maximum size limit of 0.002 mm and the approximate organic content recorded as solution loss by treatment with hydrogen peroxide. The percentages given are on the basis of the oven-dry sample.

The mechanical analyses reveal that two distinct groups are represented by the soils of the eight erosion stations—those in which the texture is variable within the profile and those with uniform texture throughout. To the former group belong Kirvin fine sandy loam, Vernon fine sandy loam, and Cecil sandy clay loam. These soil profiles are separated on the basis of horizons, and the Kirvin profile presents the A horizon (0 to 12 inches), the B_1 (12 to 24 inches), the B_2 (24 to 51 inches), the B_3 (51 to 63 inches), and the C_1 (63 to 75 inches). The Vernon profile is divided into the A_1 (0 to 3 inches) and the A_2 (3 to 10 inches) horizons, the B horizon (10 to 27 inches), and the C horizon (27 to 58 inches). The Cecil profile presents the A (0 to 6 inches), the B_1 (6 to 32 inches), and the B_2 (32 to 60 inches) horizons. The C horizon is not represented. These terms will be used in referring to the various samples.

The A horizon of the Kirvin soil and the A_1 of the Vernon are almost identical in texture. The B_1 and B_2 horizons of the Kirvin and the B_1 and B_2 of the Cecil are very similar. The B_3 horizon of the Kirvin becomes lighter in texture and the C horizon is somewhat similar to the A horizon. The C horizon of the Vernon soil consists of the disintegrated soil material, together with considerable clay, and is exceptionally high in silt, clay, and colloid, and very dissimilar to the A_1 horizon. It may also be noted that the B horizon of the Vernon is strikingly different from the corresponding horizons of the Kirvin and Cecil soils. Corresponding similarities and differences in erosional characteristics of these soils may therefore be expected. Soils of this group are characterized by sandy surface soils over light or heavy clay. They show evidences of more weathering and leaching than do the soils of the other group, but these evidences are much less marked in the Vernon than in the Cecil and Kirvin soils. The last two are to be considered as mature soils. Indeed in some respects, shown by other data, the Cecil may be considered as past maturity and approaching senility.

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TABLE 1.—*Mechanical analyses*[1] *and physical data of typical profiles of erosion-station soils*

Sample No.	Soil type	Depth	Station	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	Solution loss	Colloid 0.002 mm	Colloid by water vapor adsorption	Moisture equivalent	Dispersion ratio	Ratio of colloid to moisture equivalent	Erosion ratio	Suspension percentage	Percolation ratio	pH
		Inches		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*						
6096	Houston black clay	0-3	Temple, Tex.	0.6	0.8	0.9	4.1	4.5	26.0	60.4	2.8	44.9	41.1	30.5	10.9	1.35	8.1	9.42	6.98	8.1
6097	do	14-20	do	.3	.6	.7	3.7	4.3	25.1	64.1	1.1	46.6	40.2	27.6	5.4	1.46	3.7	4.80		8.1
6098	do	24-36	do	.3	.8	.7	3.9	4.8	27.0	61.8	.8	44.1	35.6	24.4	6.7	1.46	4.6	5.92		8.2
6099	do	36-50	do	.2	.5	.6	5.6	7.1	31.0	54.6	.3	36.2	26.7	20.6	10.1	1.30	7.8	8.68		8.2
6678	Kirvin fine sandy loam	0-12	Tyler, Tex.	2.6	1.0	2.9	43.8	24.9	15.5	8.5	.9	5.6	5.9	7.9	37.7	.75	50.2	9.04	12.05	6.2
6679	do	12-24	do	1.2	.6	1.5	14.7	13.1	7.3	60.9	.9	59.4	56.6	30.5	13.4	1.86	7.2	9.15		4.5
6680	do	24-51	do	.0	.2	1.0	10.4	25.3	9.6	53.4	.2	50.0	49.5	28.5	12.4	1.74	7.1	7.84		4.2
6681	do	51-63	do	.0	.4	1.9	18.0	31.0	13.2	35.4	.0	32.3	32.8	21.2	16.6	1.55	10.7	8.05		3.8
6682	do	63-75	do	.3	.4	.6	38.1	48.5	2.8	9.2	.0	7.3	10.0	6.7	24.9	1.49	16.7	2.99		4.0
6718	Vernon fine sandy loam	0-3	Guthrie, Okla.	.2	.2	1.3	45.1	25.3	18.2	8.0	1.8	5.2	7.4	9.6	23.7	.78	30.3	6.20	7.95	7.6
6719	do	3-10	do	.2	.2	11.3	37.5	25.0	12.9	12.0	.8	9.9	8.3	9.1	17.3	.91	19.0	4.31		7.0
6720	do	10-27	do	.2	.2	1.2	37.9	20.3	12.3	27.0	.9	23.8	21.5	17.7	16.7	1.21	13.8	6.57		6.4
6721	do	27-58	do	.0	.0	.0	14.0	18.1	34.8	32.2	.9	27.4	19.4	18.4	25.9	1.05	24.7	17.36		6.7
6797	Shelby silt loam	0-7	Bethany, Mo.	1.0	3.4	5.4	9.3	6.1	44.5	27.0	3.5	24.3	23.1	24.5	27.1	.94	28.8	19.36	20.60	5.4
6798	do	8-12	do	1.2	2.9	3.9	6.4	4.6	27.1	51.8	2.1	48.7	49.6	34.9	13.2	1.42	9.3	10.45		5.6
6799	do	12-20	do	1.3	2.9	4.1	6.9	4.9	28.5	50.2	1.2	45.4	49.4	34.2	16.0	1.44	11.1	12.56		7.0
6800	do	20-24	do	1.9	4.8	6.1	10.7	7.7	26.9	41.8	.2	37.8	37.2	27.1	22.6	1.37	16.5	15.52		8.2
6801	do	24-48	do	2.7	5.9	7.1	11.2	8.2	28.3	36.5	.2	29.7	27.0	23.0	28.3	1.17	24.2	18.31		8.6
6802	do	48-60	do	2.4	5.1	6.4	11.4	8.0	29.5	37.2	.0	31.0	26.8	22.9	27.8	1.17	23.8	18.50		8.6
6802A	Shelby silt loam (sand pocket)	48	do	4.6	14.0	18.4	18.5	6.3	16.4	21.7	.1	18.5	16.5	16.1	41.4	1.02	40.4	15.76		8.7
6802B	Shelby silt loam	60-84	do	2.0	5.1	6.4	15.8	5.5	29.2	36.1	.0	36.6	27.3	31.7	40.2	.86	46.7	26.23		8.7
6842	Colby silty clay loam	0-10	Hays, Kans.	.2	1.0	1.4	2.9	12.6	45.2	34.0	2.7	30.2	32.1	27.3	15.3	1.18	13.0	12.14	10.28	8.3
6843	do	10-20	do	.3	.8	1.4	2.9	13.2	42.3	38.0	1.1	32.4	30.7	25.2	10.8	1.22	8.8	8.66		8.4
6844	do	20-33	do	.2	.3	.5	1.9	11.0	47.0	38.7	.4	30.3	29.0	24.1	18.8	1.20	15.7	16.10		8.5
6845	do	33-47	do	.1	.4	.8	.2	10.5	47.7	38.2	.4	28.6	29.1	23.6	24.3	1.23	19.8	20.89		8.5
6846	do	47-60	do	.1	.2	.5	1.5	8.3	50.8	38.3	.3	29.0	29.9	24.8	35.7	1.21	29.5	31.81		8.5
6847	do	60-72	do	.1	.5	1.8	4.2	11.4	46.1	35.7	.3	26.8	26.5	23.7	33.6	1.12	30.0	27.47		8.5
6977	Cecil sandy clay loam	0-6	Statesville, N. C.	2.1	6.8	9.2	20.3	13.4	20.2	25.5	2.7	17.3	20.0	20.0	22.9	1.00	22.9	10.48	10.48	5.6
6978	do	6-32	do	1.5	4.5	5.3	11.6	7.7	12.0	56.7	.7	51.2	45.7	26.6	11.3	1.72	6.5	7.74		4.9
6979	do	32-60	do	2.6	4.2	3.9	9.0	6.4	17.1	56.8	.0	48.6	50.0	28.7	9.6	1.74	5.5	7.08		4.6
8069	Palouse silt loam	0-20	Pullman, Wash.	.0	.1	.1	.3	5.9	64.0	27.5	2.1	24.0	26.4	25.1	20.4	1.05	19.4	18.63	17.75	6.7
8070	do	20-33	do	.0	.1	.1	.4	5.3	55.6	37.5	1.1	33.8	35.6	27.8	16.2	1.28	12.7	15.10		6.9
8071	do	33-62	do	.1	.1	.1	.3	5.4	58.2	35.4	.4	32.0	35.8	27.6	21.6	1.30	16.6	20.20		7.0
8072	do	62-75	do	.0	.2	.1	.3	6.6	63.0	29.8	.2	26.6	30.4	25.5	28.6	1.19	24.0	26.70		7.1

8073	----do----------	75–84	----do----------	.0	.2	.1	.4	5.9	64.0	29.2	.3	25.9	30.8	25.5	26.2	1.21	21.7	24.30	--------	7.3
8736	Marshall silt loam	0–13	Clarinda, Iowa.	.1	.1	.1	.2	1.6	59.0	35.3	3.6	32.4	33.9	30.1	16.1	1.13	14.2	15.21	13.46	5.5
8737	----do----------	13–24	----do----------	.0	.1	.1	.2	1.1	56.5	39.4	2.7	34.6	39.4	31.8	7.9	1.24	6.4	7.58	--------	5.6
8738	----do----------	24–45	----do----------	.0	.5	.6	.8	1.6	61.6	33.8	1.1	28.2	33.1	29.3	18.2	1.13	16.1	17.37	--------	5.6
8739	----do----------	45–71	----do----------	.6	3.5	3.9	4.4	5.7	55.2	26.5	.2	20.3	21.4	23.3	31.8	.92	34.5	26.00	--------	5.7

[1]Determinations by L. T. Alexander, H. W. Lakin, and T. M. Shaw.

The second group comprises Houston black clay, Colby silty clay loam, Palouse silt loam, and Marshall silt loam. These soils are characterized by a very striking uniformity of texture throughout their profiles. Shelby silt loam is also included in the group, though its profile is not quite so uniform as those of the other soils. These soils all belong to the prairie and chernozem groups and show no true horizonal characteristics. The various depth limits of the parts of each profile are given in the table and will be referred to as strata, or layers.

The Colby profile is unusually uniform in texture, there being less than 4 per cent variation in the clay content of the various strata. This textural uniformity is the more striking when we consider the variations in organic matter and carbonate content in the different layers, as shown in Table 2.

Houston black clay is also almost uniform in texture in the upper three layers, but in the fourth there is a decrease in both clay and colloid. This soil contains the highest clay content of the series under consideration and shows the widest divergence between clay and colloid—a difference ranging between 15 and 18 per cent in the different layers. Whether this difference is due to the existence in the soil of a large proportion of noncolloidal clay or to the cementing effect of the colloidal calcium carbonate does not appear from the evidence. That the latter is the case seems probable from the fact that hydrogen peroxide treatment of the soil is ineffective in removing organic matter but becomes effective when the carbonates are removed. In either case the relatively large particles of clay may be expected to influence the erosional character of the soil. This soil, as shown in data given in Table 2, is remarkably high in carbonate content throughout the profile, and the data in Table 3 show a very considerable fraction of the carbonate to be in colloidal form.

The Marshall profile offers about the same textural variation in the first three layers as does the Houston profile. The fourth layer, which consists largely of glacial-drift material, differs sharply in many particulars from the upper layers which are of loessial origin. This textural difference in the deeper strata has its bearing on the erosional characteristics of the soil, as shown both by laboratory data and field behavior.

The Palouse profile, though reasonably uniform, shows a closer similarity between the first and fifth strata than these show to the other layers. The chief difference between the first and fifth layers is in the solution loss, that is, in the organic content. The difference between the upper layer and those beneath it seems to be due to eluviation and not to differences in the character of the colloid content, as will be pointed out in connection with the discussion of the composition of the colloids. The textural differences shown are such as not to indicate marked erosional differences at different levels in this soil.

The Shelby profile shows sufficient differences between the first and second layers to place it in the group of soils with divergent profile characteristics, but the remainder of the soil layers proper are very similar. When the lower layers are reached, these, except the

sand pocket represented by sample No. 6802A, are again similar in texture. The wide textural differences between Shelby silt loam and Marshall silt loam are to be ascribed to the differences in soil material noted in the soil descriptions. The influence of the drift material appears in the lowest layer of the Marshall soil, and in this layer the similarity of the two profiles appears. These textural variations may be expected to find reflection in erosional characteristics, particularly when the lower levels are reached.

In a previous bulletin Middleton (*17*) has called attention, through a study of soils of known qualitative erosional character, to certain relations of the physical characteristics of soils which are indicative of erosional behavior. The soils of the erosion experiment stations have been subjected to the same determinations, and from the data the relationships in question have been calculated. These data and ratios have been included in Table 1 with the mechanical analyses.

The colloid by water-vapor adsorption (*21*) is determined because, although in general it gives numerical values not greatly different from those obtained by mechanical analysis, it affords a direct measure of the relation of the soil to the humidity of the air. It is, in this respect, independent of the accuracy with which the colloid is determined and of size definition. The values obtained are dependent on the character of the colloid, at least to some extent, and, except for the precedent established in the previous bulletin, it would perhaps be as well to use the value of water-vapor adsorption directly determined without conversion by an arbitrary factor to presumed colloid content.

The moisture equivalent (*2*) is dependent on the sand, silt, and noncolloidal clay, as well as on the colloid content. It measures the tenacity with which moisture is held by soil and, by implication, the avidity with which it is adsorbed when opportunity offers.

The suspension percentage used in determining the dispersion ratio[3] is a measure of the behavior of soil with quantities of water in excess of the adsorbent power of the soil. It is measured arbitrarily by determining the fraction of the soil which remains suspended for a specified time when dispersed under specific conditions. The method, as described (*17, p. 2–3*), is as follows:

> A sample of air-dry soil equivalent to 10 grams of oven-dry soil was placed in a tall cylinder of approximately 1,200 cubic centimeter capacity fitted with a rubber stopper. Sufficient distilled water was added to make the volume a liter. The cylinder was closed with the stopper and was shaken end over end 20 times. The suspension was then allowed to settle until a 25 cubic centimeter sample which was pipetted at a depth of 30 centimeters consisted of particles of a maximum diameter of 0.05 millimeter. * * * From the dry weight of the pipetted fraction, the total weight of silt and clay in the suspension was calculated.

This quantity divided by the weight of the soil multiplied by 100 is the suspension percentage.

This empirically determined value is a measure of the ease of dispersion and of the rapidity of deposition of a soil. It is probable that any accurate measure of this relation carried out under specific conditions would give like relative values. This relation gives a quantitative expression to the behavior of a soil in the presence of water in excess of that required for saturation.

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[3] The suspension percentage and the dispersion ratio are similar to the dispersion factor of Puri and Keen (*20*) and the dispersion coefficient of Puri (*19*), respectively, except that they take 0.002 mm as the point of division rather than 0.05 mm as used by the writers.

These relations, including the texture measurements, give laboratory measurements for all the soil characteristics which are believed to be involved in erosion, except structure. No quantitative, or even qualitative, expression involving structural effects on erosional behavior has been formulated. It is certain, however, that so far as the structural units are not destroyed by the process of determining the suspension percentage, these units influence the value so determined.

The dispersion ratio, given in Table 1, is the ratio, expressed in percentage, of the suspension percentage to the percentage of the total silt and clay in the soil, as determined by mechanical analysis. This ratio is the fraction of the silt and clay which is most easily removed by water, and since it is to be assumed that through erosion the lighter particles, the silt and clay, are the particles most extensively removed, it would seem to follow that in a series of soils in which all other conditions are the same, the values of this ratio would express the relative erosivity of the soils. Such conditions do not in fact occur.

The ratio between the colloid and the moisture equivalent is a direct comparison of these values. When the ratio of these values is low, it is to be inferred that the colloid in question adsorbs water more readily or holds it more firmly than when the ratio has a higher value. It is, therefore, a measure of the degree of adsorption of water per colloid unit and indirectly of the relative effect on run-off produced by the colloid.

The erosion ratio is the quotient obtained by dividing the dispersion ratio by the colloid-moisture equivalent ratio. The dispersion ratio is independent of the texture of the soil, but it is dependent on the mobility of those particles most easily moved by water movement in the soil. The colloid-moisture equivalent ratio, on the other hand, is not independent of the texture since the moisture equivalent is to a large degree dependent on the space dimensions, which, in turn, are determined by soil-particle size. In the previous study by Middleton (*17*) it was found that these ratios tend to vary inversely and that when their relation to each other is considered, high values are shown for soils known to be readily eroded, and, conversely, soils not readily eroded give low values. This inverse relation appears to depend on the facts that when soils disperse readily, the erosion tendency increases and that any condition which diminishes the relative run-off likewise diminishes the opportunity for movement of material.

The erosion ratio has so far only qualitative application but in that connection has not failed, in any case, to qualitatively differentiate erosive from nonerosive soils. To what degree it is a quantitative expression can only be learned when sufficient data from field observations have been accumulated.

The percolation ratio (*26*), developed in an attempt to find a laboratory method for determining the field percolation rates of soils, is the ratio between the suspension percentage and the colloid-moisture equivalent ratio. It is held to be of qualitative significance, and present data indicate that it is applicable only in the comparison of surface soils. That it indicates permeability seems to depend on the fact that in the more easily dispersed soils the muddy percolation waters more effectively close the naturally occurring water passageways with silt and colloid. The effect obviously decreases with in-

creasing depths because of the deposition of suspended material, as well as because of other conditions in the lower horizon, which tend to produce a less porous structure.

When soils are air-dry, the presence in them of air may be expected to have an effect on their water relationships, and this effect should vary not only with the size of the interstitial spaces but also with the character of the successive strata through which gravitational water seeks to pass. That such effect is produced has been demonstrated in this laboratory, but the incomplete data obtained are not yet ready for publication. It appears, however, that all percolation data obtained by the use of open tubes are afflicted with an error of undetermined magnitude, owing to the fact that soils in the field are not provided with free flow after leaving a given fraction of the profile. Therefore, although it is obvious that the percolation rate is a factor which affects erosional behavior, it is not at all certain that the properties of the soil which influence it are reflected by the determined data.

The pH values of the soils of the erosion stations have been included with the physical data. The known effect of moderate alkalinity on the dispersability of soils would lead to the expectation that, other conditions being equal, the acid intensity would affect erosional behavior. Such equality of conditions can not be expected to occur often with simultaneous differences of pH. It may therefore be remarked at once that, although these soils furnish a pH range between the extreme values of 3.8 and 8.7, no direct relationship to erosional behavior has been established.

Examination of the data given in Table 1 shows a fairly wide variation in the colloid content, as indicated by water-vapor adsorption and moisture equivalent, and suspension percentage. These variations are reflected in the ratios determined. Were the other great soil groups represented by the station soils, the variation in properties would probably be much more diverse and the study of them of increased value. It may be remarked, however, that the stations were located primarily because of recognized injury through erosion, and the soils are therefore to be expected to be, for the most part, of highly erosional character. The erosional characteristics of a soil are not the only factors involved in the damage which is produced, since the quantity and character of rainfall and the kind of agriculture and the methods employed also have bearing on the results. It is to be noted then that the soils represented are not all easily eroded, at least throughout the profile. The most striking fact which appears in the erosional data is the lack of uniformity within the profiles even when texturally they are uniform. The colloid by water-adsorption and moisture-equivalent values follows textural uniformity when it occurs, but the suspension percentage most decidedly does not.

Normally it may be considered that the part of the soil of paramount importance to erosional behavior is the surface layer, or horizon. It must not be forgotten, however, that the lower strata have a decisive bearing not only on the total damage due to erosion, but that they also frequently determine the type of erosion which occurs. The soils of the stations furnish two groups so far as their surface layers are concerned, but the grouping is not the same as that of the textural relationships. The Houston, Colby, and Marshall surface

soils are least erosive, as indicated by the erosion ratio, and the erosivity increases by steps through the Palouse, Cecil, and Shelby soils to the most erosive surface layer, that of the Kirvin soil.

It seems desirable to consider each soil profile with respect to the physical data and to relate these to what is known of the field behavior of the soils. It is hoped that these considerations may help to point out the missing data which are needed, the field observations which should be made to obtain a clearer picture of the relations between soil composition and erosional behavior, and to point the way to the most helpful methods of control.

The Houston soil has an exceptionally low erosion ratio which, by comparison with that of the other soils, is remarkably uniform throughout the profile. Nevertheless, its surface layer is much more erosive than the layer lying immediately below. These relations would seem to require that erosion of the Houston soil should be uniform and of the kind known as sheet erosion, since gullying is produced by reason of marked increase in erosivity of some stratum lying beneath the subsoil. The soil data given class this soil as relatively nonerosive, but as the discussion of the plot data (Table 7) indicates, the field data show extensive damage. This damage appears to be owing to a group of influences not considered at all or only in part by the measurements given. The pH of the soil is high, largely because of the calcium content. This results in a low relative suspension percentage. On the other hand, the very large content of clay and its high shrinkage value, not included in the determinations made, produce extensive cracking of the soil on drying, and, so far as the surface soil is concerned, results in the production of a fine, granular structure the component units of which are cemented by colloidal carbonates. The result is that a highly fluid suspension of these fine particles readily forms on the surface and follows the lines of drainage, in which are included the large subsoil cracks previously mentioned. A striking peculiarity of the Houston clay, at least in the neighborhood of the experiment station, is the sinusoid character of the line of cleavage between the second and third layers of the soil. Whether this has been produced through erosion or is due to some other cause, the result is an irregular exposure of subsoil on the surface as erosion proceeds, with consequent effect on soil productivity. In addition to these soil characteristics the rainfall of the region occurs at infrequent intervals and is torrential in character. The relative run-off is therefore excessive, and the carrying power of the moving water is likely to be high because of the velocity of the flow. These conditions, taken together, result in greater soil injury than would be indicated by the soil characteristics given in Table 1.

The Colby soil has erosional properties somewhat higher than those of the Houston but is still to be classed, on the basis of these properties, as a nonerosive soil particularly as respects the upper layers. However, its surface soil is more erosive than the stratum immediately beneath it. When the profile characteristics are considered in conjunction with the low rainfall it appears that, so far as erosion occurs, it should be sheet erosion, and when the calcium carbonate content is considered, together with the high plastic clay content with the consequent fine granulation of the surface soil when dry, wind erosion is indicated. However, were the rainfall sufficient

to produce continuous run-off, gully formation would occur with rapidity after the depth of cutting had exceeded 4 feet. That such erosion does not occur is doubtless due to the amount and also the character of the precipitation. The greater suspension percentage of the surface layer, as compared with the subsoil of both the Colby and the Houston soils, as well as that of the Marshall soil, although the other data are uniform, is doubtless to be associated with the structural relations produced by air drying. The finely granulated surface-soil particles disperse more readily than the larger granules of the subsoil. This difference disappears when the soil samples are taken when the surface soil is moist. (See composite-plot data.)

The Marshall soil, like the Houston and Colby soils, shows a striking contrast between the surface soil and the subsoil in suspension percentage, and therefore in the erosion ratio, though otherwise the two layers are similar. As already mentioned, this indicated difference in erosional behavior is reflected in the observed field behavior of the soil, although the measurements based on the plots have not, as yet, been received. The streams in this area, as is usual in prairie regions, are notably turbid with suspended colloid. The explanation of the indicated erosional difference between subsoil and surface soil is, as before, to be attributed to structural differences. The air-dry surface soil becomes extremely fine and in consequence is more readily suspended and removed by flowing water than the more compact subsoil. The data would also indicate the probability of lateral water movement occurring not only at the surface but, with sufficient rainfall, also at the surface of the subsoil, and in cultivated fields at plow depths. So far as this occurs, the removal of the surface soil is greatly accentuated. The data also indicate that when gullies are cut to the level of the glacial drift, undercutting occurs, owing to the greater erosivity of the drift, and the gullies become U-shaped, with overhanging projections of the upper strata.

The Palouse soil has somewhat greater erosional character than the Marshall. The data for this soil do not indicate a highly erosive material, but because of the steep slopes on which it occurs, the soil is subject to damage from erosion to a degree probably not commensurate with the rainfall. The difference between the surface layer and the second layer, in suspension percentage and erosion ratio, is not so marked as in the soils so far considered. It is to be noted, however, that the surface layer is of unusual depth. There are notable differences also in the other soil characteristics, especially in the silt and clay content. It is therefore difficult to say to what extent the erosional differences are due to structural differences. The data lead to the belief that even if the rainfall were adequate, gully formation would not readily occur.

The Cecil soil, as already mentioned, is exceedingly nonerosive so far as its B_1 and B_2 horizons are concerned. The relatively high erosional characteristics of the A horizon are to be ascribed in part to the lack of structure, which accompanies the high silt and sand content, in contrast with the low colloid content which results in a higher suspension percentage in the A than in the B horizons. The numerical value of the colloid-moisture equivalent ratio of the surface soil

apparently is due to the organic matter and to the retentive capacity for water of the silt and very fine sand being added to that of the colloid itself. This textural difference is reflected in the erosion ratio. The soil damage from erosion in the Cecil areas is accentuated by the relatively high rainfall as well as by the type of agriculture. The chief crops are cotton, tobacco, and corn, and grass or other cover crops are not common. The result is that much of the Cecil area now has no A horizon. These mutilated profiles are nonerosive. The data given in Table 1 do not include the C horizon and therefore no indications of the relation of the soil to gully formation are presented. Since, however, the description of the soils notes gully formation on steep slopes, it is to be inferred that the erosional characteristics of the C horizon are more marked than those of the B horizon.

The Shelby soil presents an interesting profile in that its surface layers offer the same relationships in general as those of other prairie soils. In the lower strata are found increased sandy components of coarser type. These result in low values for the colloid-moisture equivalent ratio and the dispersion ratio. As a consequence, the erosion ratio is increased. These indications are reflected in the field by the formation of deep gullies with overhanging ledges of the less erosive intermediate layers, and they include at times the surface layer which, although somewhat more erosive than the layers beneath it, is often held in place by grass roots.

The suspension percentage of the surface layer is high, a fact reflected by the turbid condition of surface water even when flowing through meadows. The relative erosivity of the surface layer is much higher than that of the second layer. This difference is clearly attributable in part to textural differences in silt and clay content but must also be attributed in part to the structural differences already noted in the other prairie soils, since the lower strata, which do not show the textural differences so markedly, gradually increase in erosional character.

The Vernon soil has a low content of silt and clay in the A_1 and A_2 horizons, the fine sand and very fine sand being correspondingly high. In consequence the moisture equivalent is low. Nevertheless the colloid-moisture equivalent ratio is very low by reason of the retention of moisture by the noncolloidal parts of the soil, which are relatively very large. The suspension percentage is numerically low but, relative to the total silt and clay, it is very high. The result is a high dispersion ratio. The combination of these ratios necessarily results in a high erosion ratio for both parts of the A horizon. The suspension percentage of the A_1 horizon is, however, relatively much greater than that of the A_2, with consequent normal relation of greater erosivity for the surface layer. The B horizon has a numerically higher suspension percentage than the A_1 and A_2 layers, but relative to the total clay and silt content it is much smaller. The colloid-moisture equivalent ratio is greater than in the upper strata. We have, therefore, a gradually decreasing erosion ratio through the A and B horizons. The C horizon contains, in addition to the disintegrated soil material, considerable quantities of weathered clay, and, although it is somewhat more erosive than the B horizon, the relative difference between the lowest stratum and those above it, so far as the erosion ratio is concerned, is not exceptionally marked.

We have in this soil, therefore, the conditions for ready gully formation of the V-shaped type. Because of the low colloid content of the surface soil, erosion is particularly destructive in this soil whenever the surface is not protected by a vegetative cover.

The Kirvin soil is characterized by the highest erosion ratio for the surface soil of any of the soils of the stations and by the strongest contrast between the A and B horizons. The A horizon has its abnormally low content of colloid associated with the water-holding capacity of the silt and sands. The colloid is relatively nonplastic. The suspension percentage of the A horizon is abnormally high, being, in fact, greater than the total amount of clay present. This may be taken to mean that the soil is readily dispersed, despite the low silica-sesquioxide ratio. (Table 3.) It would seem that the colloid may be regarded as dispersed in the sand. The gravel content and the presence of stones, of greater than gravel size, also favor rill formation. We have then in the surface soil most favorable conditions for erosion. The contrast with the erosion ratios of the B horizon can at once be ascribed in part to the difference in suspension percentage. Although the numerical value is slightly greater in the B horizon than in the A horizon, it is actually less than one-seventh of the clay content. To what extent this low suspension percentage is due to structure is not known, but the clay is brittle, and the soil is not readily penetrated by water by reason of the high clay content. We have, therefore, in this soil the conditions for gully erosion of the V-shaped type. Also, as in the Vernon soil, there is special susceptibility to damage through erosion since the colloid content of the surface soil is low.

Taken as a whole, the soils of the erosion stations offer a very interesting variety of physical properties and consequent erosional characteristics. Continued study of these will throw much additional light on the conditions which determine erosional behavior. It is unfortunate for this purpose that the station soils do not offer a more varied assortment of soil classes and do not present examples of more soil groups of widely divergent character.

Throughout the study of these profiles the bearing of structural relations on the erosional behavior of the soil has impressed itself on the writers. At present the expressions of variations in structure are so lacking in quantitative significance as to render hopeless any attempt to evaluate their relation to the other influences which affect erosional behavior. The study of this phase of the subject will amply reward the investigator who is able to develop a satisfactory method of approach.

CHEMICAL COMPOSITION OF THE SOILS

The complete chemical analyses of the whole soil, which are given in Table 2, are perhaps less significant of erosional relations than the physical data and the colloid data given in Tables 1 and 3. They are recorded for the purpose of presenting all possible chemical data on the soils. Without these analyses of the soils the chemical analyses of the colloids and the mechanical analyses of the soils do not present a complete picture of the genetic and classification relations of the soils on which the erosion stations are located. A discussion of these relations is necessarily deferred until the colloid analyses have been presented.

TABLE 2.—*Chemical analyses of typical profiles of erosion-station soils*

Sample No.	Soil type	Depth	Station	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	Ignition loss	Total	N_2	CO_2 from carbonates	Organic matter	Ratio of organic matter to nitrogen
		Inches		*P. ct.*	*P. ct*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	
6096	Houston black clay.[2]	0-3	Temple, Tex.	24.74	0.34	2.68	6.69	0.03	32.81	1.23	0.65	0.21	0.34	0.31	30.30	100.33	0.18	25.09	2.94	16.3
6097	do	14-20	do	22.80	.32	2.84	6.96	.05	34.34	1.13	.50	.27	.36	.25	30.52	100.34	.11	25.82	1.88	17.1
6098	do	24-36	do	19.91	.32	2.65	6.06	.05	37.25	.95	.48	.19	.40	.25	31.72	100.23	.06	29.16	1.10	18.3
6099	do	36-50	do	13.17	.24	2.55	4.48	.04	42.52	.94	.39	.29	.44	.28	34.90	100.24	.04	33.88	.51	12.8
6678	Kirvin fine sandy loam.[3]	0-12	Tyler, Tex.	91.63	.49	3.76	2.06	.02	.18	.15	.32	.06	.07	.08	1.68	100.50	.04	.00	.54	13.5
6679	do	12-24	do	61.89	.57	9.95	18.15	.008	.16	.48	.51	.10	.13	.13	7.45	99.53	.05	.00	.81	16.2
6680	do	24-51	do	69.90	.62	7.55	15.51	.006	.30	.40	.51	.00	.10	.16	5.21	100.27	.02	.00	.24	12.0
6681	do	51-63	do	80.06	.57	4.98	10.29	.006	.08	.34	.35	.00	.07	.12	3.28	100.15	.01	.00	.14	14.0
6682	do	63-75	do	91.65	.26	3.38	2.98	.003	.10	.14	.46	.00	.04	.11	1.13	100.25	.01	.00	.05	5.0
6718	Vernon fine sandy loam.[3]	0-3	Guthrie, Okla.	90.81	.35	1.68	3.42	.07	.10	.31	.70	.10	.06	.12	2.34	100.06	.08	.90	1.81	22.6
6719	do	3-10	do	90.28	.40	1.76	4.14	.05	.36	.42	.60	.06	.05	.07	1.40	100.13	.03	.00	.62	20.7
6720	do	10-27	do	83.96	.44	3.92	7.70	.06	.36	.66	.99	.15	.05	.07	2.32	100.67	.04	.00	.63	15.7
6721	do	27-58	do	80.32	.76	2.60	10.35	.018	.28	.81	1.38	.26	.08	.04	2.61	99.51	.02	.00	.28	14.0
6797	Shelby silt loam.[3]	0-7	Bethany, Mo.	75.91	.62	3.95	9.13	.02	.82	.63	1.50	1.72	.29	.23	5.42	100.24	.16	.02	3.23	20.2
6798	do	8-12	do	66.54	.63	6.45	14.33	.04	.95	1.14	1.38	1.41	.30	.30	6.80	100.27	.11	.01	2.17	19.7
6799	do	12-20	do	68.75	.71	6.03	14.05	.03	1.06	1.16	1.38	1.55	.12	.17	5.24	100.25	.09	.07	1.59	17.7
6800	do	20-24	do	68.25	.64	6.30	13.62	.03	1.64	1.17	1.47	1.64	.44	.11	5.03	100.43	.07	.32	.82	11.7
6801	do	24-48	do	65.12	.54	4.38	10.30	.06	7.05	1.15	1.39	2.03	.45	.16	7.67	100.30	.03	5.05	.27	9.0
6802	do	48-60	do	65.84	.55	4.64	10.23	.03	6.74	1.03	1.38	1.63	.30	.17	7.41	99.95	.02	4.85	.14	7.0
6802A	Shelby silt loam.[2] (sand pocket).	4 feet.	do	71.09	.44	5.30	8.56	.05	4.34	1.57	1.43	1.75	.36	.11	5.37	100.37	.02	3.24	.18	9.0
6802B	Shelby silt loam.[2]	60-84	do	66.65	.62	6.52	9.95	.04	5.20	1.32	1.67	1.55	.46	.14	6.00	100.12	.02	4.08	.07	3.5
6842	Colby silty clay loam.[3]	2-10	Hays, Kans.	68.50	.62	3.52	11.70	.07	4.30	1.11	2.58	.98	.16	.14	6.49	100.17	.15	2.98	2.82	18.8
6843	do	10-20	do	62.92	.53	2.40	11.55	.06	8.22	1.09	2.27	.90	.15	.14	9.63	99.86	.07	6.07	1.11	15.9
6844	do	20-33	do	59.76	.49	2.64	11.00	.06	10.54	1.17	1.87	1.02	.14	.14	10.75	99.58	.04	7.55	.65	16.2
6845	do	33-47	do	59.30	.53	2.64	11.35	.05	11.08	1.19	2.23	1.08	.19	.15	10.30	100.09	.03	8.27	.32	10.7
6846	do	47-60	do	61.50	.53	3.04	12.35	.06	10.00	1.25	2.27	1.17	.16	.14	8.60	101.07	.03	7.32	.13	4.3
6847	do	60-72	do	61.20	.53	3.52	10.06	.06	10.80	1.15	2.38	.87	.17	.14	9.53	100.41	.03	7.90	.14	4.6
6977	Cecil sandy clay loam.[3]	0-6	Statesville, N. C.	75.06	1.24	4.16	10.80	.21	.32	.36	.51	.04	.12	.10	6.84	99.76	.09	.00	3.21	35.7
6978	do	6-32	do	61.12	1.33	9.76	19.56	.06	.28	.29	.59	.03	.14	.11	7.30	100.57	.04	.00	.45	11.3
6979	do	32-60	do	57.32	1.51	11.20	22.16	.06	.26	.28	.43	.00	.13	.17	7.27	100.79	.04	.00	.34	8.5
8069	Palouse silt loam.	0-20	Pullman, Wash.	66.15	.85	5.42	14.69	.15	1.77	.76	2.34	1.93	.28	.03	5.22	99.59	.13	.00	2.18	16.7
8070	do	20-33	do	65.40	.82	5.65	15.90	.15	1.61	.95	2.06	1.76	.30	.02	4.96	99.58	.12	.00	.96	8.0
8071	do	33-62	do	66.10	.82	5.73	16.01	.15	1.65	1.04	2.06	1.80	.16	.02	4.43	99.97	.05	.00	.46	9.2
8072	do	62-75	do	66.90	.82	5.63	15.79	.16	1.79	.93	2.07	1.81	.16	.00	3.85	99.91	.04	.00	.36	9.0

8073	----do----	75–84	----do----	67.10	.82	5.70	15.71	.16	1.88	1.03	2.10	1.85	.17	.00	3.71	100.23	.03	.00	.27	9.0
8736	Marshall silt loam	0–13	Clarinda, Iowa	70.70	.69	4.10	12.44	.12	.89	.78	2.16	1.21	.22	.08	6.87	100.26	.19	.00	3.22	17.0
8737	----do----	13–24	----do----	69.85	.73	4.36	13.42	.14	.91	1.00	2.12	1.01	.16	.12	6.21	100.03	.13	.00	2.29	17.6
8738	----do----	24–45	----do----	72.60	.70	3.92	13.07	.12	.98	.72	2.05	1.03	.14	.08	4.40	99.81	.07	.00	.96	13.7
8739	----do----	45–71	----do----	78.75	.66	2.94	10.23	.10	.83	.64	1.83	1.03	.13	.06	2.85	100.05	.06	.00	.46	7.7

[1] CO_2 time factor of 0.471.

Determinations by J. G. Smith.

[2] Determinations by G. J. Hough.

Aside from this major purpose, these analyses offer certain items of information not shown by any of the other data. These will be summarized, but before doing so two items regarding the analyses should be noted. These have reference to the organic-matter and carbon-dioxide determinations.

The organic matter was determined by combustion, using the conventional factor of 0.471 to convert carbon dioxide percentages to organic matter. They are therefore subject to the inaccuracies inherent in this factor. Carbon dioxide from carbonates was determined only in those horizons which gave qualitative evidence of the presence of carbonates. Consequently, a number of profiles are shown as having no carbonates when undoubtedly traces would have been shown to be present under the more exact procedure described by Alexander and Byers.[4]

The discussion of the chemical analyses of these soils as here presented is admittedly brief, but the attempt has been to eliminate from the discussion those items which must necessarily be repeated in a discussion of the colloids of these soils. In discussing the chemical analyses of the colloids, constant reference will be made to the chemical analyses of the soils as well as to the mechanical analyses.

Percentages of calcium carbonate show considerable variation in the different types of soil. The samples of the Kirvin, Vernon, Cecil, Palouse, and Marshall soils contain no carbonates, or, at the most, but traces. The lower layers of the Shelby soil and the entire profile of the Colby are highly calcareous. On the basis of percentages of CO_2 and CaO, the surface soil of the Houston soil contains 57 per cent of calcium carbonate, and the deepest layer of the Houston contains 75 per cent. Such high percentages of calcium carbonate profoundly affect the physical as well as the chemical properties of the soil. Where the entire soil exhibits such unusual characteristics of composition as does the Houston, the soil analysis becomes particularly informative.

The chemical analyses show that the Shelby, Colby, Palouse, and Marshall soils are particularly rich in potash, not only in the surface soil but throughout the profile. The potash content of the Houston soil decreases with depth, whereas the Vernon shows an increase in potash below a depth of 10 inches. The Kirvin and Cecil also show an increased percentage of K_2O in the B horizon. These increases are found to correspond with increases in the clay content of the soils as shown by the mechanical analyses.

The percentages of P_2O_5 in general vary but little for each profile. A relative deficiency is noted in the Shelby soil between depths of 12 and 20 inches. The Marshall, Cecil, and Palouse soils are noticeably richer in phosphorus in the upper horizons, but the lower horizons are by no means deficient in this essential plant-food element.

Values for the organic matter throughout each profile show sharp decreases at the lower depths, but the depth at which these decreases occur varies in each soil type. The Houston, Shelby, Colby, Palouse, and Marshall soils all maintain excellent percentages of organic matter to a depth of 20 or more inches. The organic matter of the

[4] ALEXANDER, L. T., and BYERS, H. G. A CRITICAL LABORATORY REVIEW OF METHODS OF DETERMINING ORGANIC MATTER AND CARBONATES IN SOILS. U. S. Dept. Agr. Tech. Bul. 317. (In press.)

Vernon and Cecil soils is largely concentrated in the surface 6 inches of soil. The Kirvin soil, which contains little organic matter at any depth, shows a higher percentage in the heavy clay B horizon than it does in the sandy surface soil. In general, the values for nitrogen parallel the values for organic matter throughout each profile.

In the last column of Table 2 are given the organic matter–nitrogen ratios for the profile of each soil. It is to be noted that there is no constant value shown, either as between the profiles or in relation to depth. Only in the Shelby soil is there a close approach to the conventional ratio of 20. The trend shows a decrease in the ratio with increasing depth. This fact for these soils is in accord with the data presented by Leighty and Shorey (*11*) and by McLean (*14*) and with the as yet unpublished data presented by Russell at the meeting of the American Society of Agronomy in November, 1931. The significance of these relations to erosion is not clear but may become evident when adequate field data are available.

So far as the chemical components of fertility are concerned, it appears that in the removal of the surface soil by erosion the most severe result will be a loss of nitrogen and organic matter. The potash and phorphorus content are, comparatively, high enough in the lower horizons to furnish a basis for the belief that for these soils, even though badly eroded, rehabilitation can be accomplished through the laborious process of building up reserves of organic matter and nitrogen. But the assumption must not be made that the potash and phosphorus content of the lower horizons is as available as that of the surface soil. These constituents become available slowly by weathering and by the action of soil bacteria in the presence of organic matter.

CHEMICAL COMPOSITION OF THE COLLOIDS

The erosion stations are established primarily for the purpose of determining the amount, causes, and means of control of erosion. However, in the course and prosecution of these studies much information will be obtained which concerns the properties and utilization of the various soils. Since the physical properties of a soil are determined, to a large extent, by the type of colloid it contains, and since erosional behavior is directly dependent on these physical properties, a careful study of the colloids of these soils has been made.

The colloids, except those of the two lower layers of the Cecil profile, were extracted without the use of any dispersing agent. To extract these colloids, sufficient ammonia was added to make the dispersed suspension approximately neutral to phenolphthalein. The dispersion was repeated from three to seven times until the yield of colloid by centrifuging was materially decreased. The "percentage of total colloid" extracted is the fraction obtained of the amount shown to be present by mechanical analysis. It is not to be expected that in any case the extracted colloid would reach 100 per cent, since the particle size limit of the extracted colloid is 1 micron and the mechanical analyses include particles up to 2 microns. The quantities obtained ranged between the values of 80 per cent for the third layer of Shelby silt loam to 42 per cent for the surface layer of Colby silty clay loam. As applied to the total colloid, the validity of the analytical data rests on the assumption that the extracted colloid is essentially the same as that not extracted. Brown

and Byers [5] have shown that essential differences do exist between the easily extractable and difficultly extractable parts of a soil colloid. However, their findings do not invalidate the above assumption, since by their methods the difficultly extractable part represents only a small fraction of the total colloid.

In all the colloids the organic matter was determined by repeated treatment with hydrogen peroxide. The values reported are therefore slightly low, but they represent the relative quantities of similar material in these profiles.

The carbon dioxide reported was determined by the use of the apparatus developed by Alexander and Byers [6] details of which are being prepared for publication. Data obtained with this apparatus indicate the small relative quantities of carbon dioxide present in colloids which are ordinarily classed as carbonate free or non-calcareous.

The colloids from the soils selected show a very wide range in chemical composition. In fact two maxima for American soil colloids are shown, the 0.90 per cent MnO for the Vernon fine sandy loam colloid, and the 15.1 per cent $CaCO_3$ (equivalent to 6.69 per cent CO_2) for the Houston black clay colloid (*24*).

In general, the analyses of the colloids of these soils show the usual relationships to the complete analyses of the soils themselves. The silica is lower and the iron and alumina are higher in the colloid fraction. The apparent exception in the Houston colloid is due to the extremely large calcium carbonate content of the soil, only a relatively small part of which appears in the colloid. A much larger relative amount of calcium carbonate is found in the Colby colloid.

It seems probable that the colloidal carbonate material is due to the solution of the carbonate as calcium bicarbonate during wet periods and its redeposition in a state of very fine subdivision on drying. The colloidal carbonate appears in all layers of both Houston clay and Colby silty clay loam. In Shelby silt loam it appears in more than traces only in the lower horizons.

In horizons which reveal only traces of carbonates the usual relation is an increase in the calcium of the colloid as compared with that of the soil. This indicates that a large part of the calcium is colloidally held. The same statement holds for all horizons of all soils for magnesium. The percentage concentration is greater for magnesium than for calcium. The difference is due primarily to the more extensive leaching of calcium.

The same tendency toward concentration in the colloid fraction is shown by the organic matter except in the surface layer of the Cecil profile. The soil sample from this horizon contains a large amount of undecomposed organic matter. A less definite trend toward concentration in the colloid fraction is shown by manganese, titanium, and phosphorus. No trend toward concentration in the colloid fraction is to be observed for sodium or sulphur. A relative deficiency in the proportion of potash-bearing material in the profiles of Houston clay, Kirvin fine sandy loam, and Vernon fine sandy loam is shown by the markedly increased percentages in the

[5] BROWN, I. C., and BYERS, H. G. THE FRACTIONATION, COMPOSITION, AND HYPOTHETICAL CONSTITUTION OF CERTAIN COLLOIDS DERIVED FROM THE GREAT SOIL GROUPS. U. S. Dept. Agr. Tech. Bul. 319. (In press.)

[6] ALEXANDER, L. T., and BYERS, H. G. Op. cit. (See footnote 4.)

colloids, as compared to the soils. This may partly, and perhaps wholly, be attributed to the presence of quartz sands in the last two soils and to the large content of calcium carbonate in Houston clay.

Further consideration of the colloid analyses shows that two widely divergent types of colloid are included. This is indicated by the silica-sesquioxide ratios and more emphatically by the silica-alumina ratios. Representative of one extreme is the colloid from Cecil sandy clay loam which is distinctly lateritic, and representative of the other is the colloid of Colby silty clay loam. The former has a silica-alumina ratio of 1.65 in the surface layer and the latter a ratio of 4.25.

Of the other colloids, those of the Houston, Marshall, Shelby, and Palouse soils have silica-alumina ratios of well above 3 throughout the profile. The Vernon colloid also appears to belong in this general group, although the silica-alumina ratio drops below 3 for the subsoil colloids.

With the exception of the Vernon, the soils of this group contain large quantities of colloidal material, and the type of colloid found in them is such as to make the soils plastic and sticky when wet and also highly impermeable to water. The fate of incident water is thus affected by the type and quantity of colloid in the soil. The effects are of course modified, as in the Houston and Colby soils, when the soils contain calcium carbonate or other flocculating material.

The only colloid which may be classed with the Cecil is the Kirvin. Although there is a good deal of difference between the two when judged by the ratios of the major constituents, the classification is justified on other data. Both colloids are red, contain much less exchangeable base than any other of the colloids under discussion, and the soils they represent are markedly acid in reaction. The Vernon colloid is also red, but in this connection it must be remembered that the Vernon soil is derived from the red shales, and color indications may, therefore, in the Vernon colloid, be deceptive. The relatively unweathered state of the Vernon soil is indicated not alone by the high silica-alumina ratio of its colloid but by the high content of exchangeable bases as well. The Vernon profile is not so acid in any horizon as the least acid of the horizons of either the Kirvin or Cecil soils. (Table 1.) To establish more completely the proper chemical classification, colloids from the B horizon of each of these soils were submitted to S. B. Hendricks for X-ray examination (*9*). He submits the following report:

> Samples Nos. 6097, 6799, 6843, 8070, 8737 (Houston, Shelby, Colby, Palouse, Marshall) are Ordovician bentonite (montmorillonite quartz). Nos. 6679, 6720, 6978 (Kirvin, Vernon, Cecil) are more complicated than ordinary clay mineral photographs, and are evidently mixtures. Of these, No. 6720 (Vernon) is predominantly Ordovician bentonite. The other two (Kirvin and Cecil) are mixtures of a clay mineral with some other substance or substances.

Any relationships shown by the inorganic composition of the colloid are also modified by the quantity, character, and distribution of the organic matter present. Such data can not be given quantitative expression at present, but it is of interest to point out that in the two calcareous soils which have organic contents not widely at variance in the surface horizons, the distribution within the profiles is

quite different. In the Shelby and Palouse profiles there is a marked difference in the organic content of the surface layers but an equally marked similarity of distribution.

The 22d column of Table 3 gives the organic matter-nitrogen ratios for the extracted colloids. In this case the organic matter was determined by the hydrogen-peroxide method, and it is known that not all of the organic matter is so removed (*22*). The ratios are therefore numerically smaller than they would be had the combustion method been employed. The outstanding relation shown by these ratios is the uniform decrease in ratio with depth. This relation may be interpreted to mean that the organic matter at lower levels has been longer subject to the processes of decay and that the nonnitrogenous material decays more readily than nitrogenous bodies. That the nonnitrogenous matter is oxidized more readily by hydrogen peroxide has been shown by McLean (*15*, *16*). This assumption is valid only so far as we assume that the organic matter at lower levels has been carried down from above. This latter assumption is not wholly true in any case and perhaps to but a limited degree in the soils not subject to podzolization. In the colloids, as in the soils, the relation between the composition of the organic matter and the erosional behavior must await fuller knowledge of data both on field behavior and the variation of composition of the organic matter.

The erosional behavior of the Kirvin, Vernon, and Cecil soils is influenced by the small content of colloid in the surface layers (Table 1), and this influence tends to obscure the effects consequent on colloid composition in these horizons. The iron-oxide content of the two colloids of highest apparent weathering, the Kirvin and the Cecil, is notably high, as shown by silica-iron oxide ratios. The data at hand do not clearly indicate what erosional relations exist between sesquioxide colloids and alumino silicates, but it is in general true that laterites and lateritic soils are not readily eroded. Of the soils under discussion, those which contain notable quantities of ferric oxide in their colloids undoubtedly have their erosional relations influenced by its presence.

Detailed examination of the profiles of these series leads to some observations which have a bearing not only on erosional behavior but also on general soil relationships. As already mentioned, the Houston soil has a very high carbonate content throughout the profile. A considerable fraction of this carbonate finds its way into the colloidal fraction in each of the successive layers. The lower layers are much richer in colloidal carbonate than the surface layers, a condition which is to be expected in a region of high rainfall, and the same general relation holds for the total carbonate content of the soil.

Except for variations in the amounts of organic matter and carbonates, the colloid of the Houston soil is essentially the same throughout the profile. This constancy is emphasized by the ratios of the major constituents as given in Table 3. Such minor variations as appear are to be found in the relative quantities of iron oxide, as shown by the silica-iron oxide and iron oxide-alumina ratios. The silica-alumina ratios are practically identical for the complete profile. This constancy of composition of the colloids of the chernozem and prairie soils has been noted by Byers and Anderson (*3*). Such variation as may occur is a measure of the extent to which podzolization or laterization has occurred.

TABLE 3.—*Chemical analyses of colloids in typical profiles of the erosion-station soils*

Sample No.	Soil type	Depth	Station	Colloid extracted	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
6096	Houston black clay	0–3	Temple, Tex	55	43.55	0.53	5.92	18.94	0.07	9.28	2.50	1.13	0.27	0.22
6097	do	14–20	do	55	41.72	.54	5.92	18.08	.07	11.73	2.41	1.11	.27	.21
6098	do	24–36	do	57	42.25	.54	5.95	18.33	.09	12.35	2.25	.99	.25	.22
6099	do	36–50	do	48	43.30	.58	6.25	18.53	.07	12.00	2.63	1.07	.27	.22
6678	Kirvin fine sandy loam	0–12	Tyler, Tex	70	41.97	.90	14.74	25.96	.10	.64	.46	.89	.48	.30
6679	do	12–24	do	77	39.95	.77	14.37	29.78	.01	.35	.69	.84	.34	.18
6680	do	24–51	do	69	42.19	.81	12.72	29.63	.01	.25	.81	.70	.36	.16
6681	do	51–63	do	55	44.30	81	11.07	30.16	.01	.19	.78	.70	.39	.15
6682	do	63–75	do	46	41.10	.79	15.96	28.30	Trace.	.04	.65	.64	.31	.17
6718	Vernon fine sandy loam [1]	0–3	Guthrie, Okla	46	42.49	1.74	9.87	20.90	.90	1.30	1.80	2.13	.67	.39
6719	do	3–10	do	72	45.03	1.90	10.70	24.44	.25	.79	1.99	2.25	.90	.28
6720	do	10–27	do	79	45.10	1.44	10.53	26.00	.15	.68	2.08	2.34	.70	.15
6721	do	27–58	do	63	46.99	.84	9.55	27.71	.05	.66	2.62	2.41	.93	.10
6797	Shelby silt loam [1]	0–7	Bethany, Mo	46	45.89	.67	9.23	23.51	.07	1.31	1.87	1.19	.21	.30
6798	do	8–12	do	73	47.49	.67	9.99	24.41	.06	1.28	1.98	1.12	.20	.12
6799	do	12–20	do	81	48.29	.68	10.31	2.490	.08	1.36	2.02	1.26	.29	.11
6800	do	20–24	do	75	47.98	.71	11.14	24.24	.09	1.62	2.17	1.31	.38	.12
6801	do	24–48	do	73	48.48	.74	11.49	23.03	.11	2.16	2.06	1.62	.44	.16
6802	do	48–60	do	53	48.26	.75	11.84	23.12	.08	2.34	2.06	1.66	.41	.16
6802A	Shelby silt loam (sand pocket)	4 ft.	do	67	47.20	.49	11.11	26.12	.11	1.80	1.93	1.80	.41	.20
6802B	Shelby silt loam [1]	60–84	do	60	49.62	.72	14.83	19.43	.10	2.22	2.12	1.88	.42	.16
6842	Colby silty clay loam	2–10	Hays, Kans	42	49.31	.52	7.10	19.67	.11	4.35	2.71	2.30	.28	.15
6843	do	10–20	do	52	46.95	.50	6.76	19.03	.11	7.68	2.77	2.09	.17	14
6844	do	20–33	do	55	48.60	.49	6.96	19.23	.12	7.26	3.07	2.11	.26	.14
6845	do	33–47	do	57	48.00	.50	6.28	19.09	.11	8.83	3.14	2.10	.37	.14
6846	do	47–60	do	52	49.00	48	6.72	19.00	.11	7.40	3.21	2.03	.23	.14
6847	do	60–72	do	43	47.20	.46	6.55	18.31	.10	10.23	3.15	2.11	.24	.13
6977	Cecil sandy clay loam	0–6	Statesville, N. C	59	32.81	1.56	12.57	33.68	.43	.66	.81	.57	24	32
6978	do	6–32	do	69	33.35	1.49	12.20	36.44	.14	.47	.63	.47	.17	.26
6979	do	32–60	do	70	35.75	1.40	16.17	32.22	.10	.47	.34	.35	.19	.31
8069	Palouse silt loam	0–20	Pullman, Wash	60	44.86	.82	11.13	23.59	.16	1.59	2.28	2.12	.32	.36
8070	do	20–33	do	77	45.73	.89	12.85	23.43	.15	1.60	2.33	1.38	.43	.25
8071	do	33–62	do	78	46.00	.86	12.20	24.07	.14	1.53	2.32	1.64	.30	.17
8072	do	62–75	do	89	47.86	.76	12.53	23.56	14	1.67	2.48	1.17	.22	.20
8073	do	75–84	do	79	48.00	.86	12.50	23.26	.14	1.69	2.48	1.46	.41	.20
8736	Marshall silt loam	0–13	Clarinda, Iowa	63	46.90	.60	9.10	21.55	.16	1.17	2.35	2.14	.09	.29
8737	do	13–24	do	66	47.69	.62	9.42	22.10	.15	1.11	2.53	1.86	.09	.22
8738	do	24–45	do	69	49.72	.65	9.86	22.63	.13	1.09	2.48	1.58	.16	.18
8739	do	45–71	do	65	49.30	.65	9.60	23.41	.13	1.02	2.31	1.69	.08	.20

[1] Analyses of these soils are averages of duplicate samples.

TABLE 3.—*Chemical analyses of colloids in typical profiles of the erosion-station soils*—Continued

Sample No.	Soil type	Depth	Station	SO_3	Ignition loss	Total	Nitrogen	CO_2 from carbonates	Organic matter	Ratio of organic matter to nitrogen in colloid	Mols $\frac{SiO_2}{Fe_2O_3}$	Mols $\frac{SiO_2}{Al_2O_3}$	Mols $\frac{Fe_2O_3}{Al_2O_3}$	Mols $\frac{SiO_2}{R_2O_3}$
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*					
6696	Houston black clay	0-3	Temple, Tex	0.19	18.09	100.69	0.38	4.91	3.86	10.2	19.56	3.90	0.200	3.26
6697	do	14-20	do	.11	18.25	100.42	.22	6.16	3.13	14.2	18.75	3.92	.209	3.24
6698	do	21-36	do	.11	16.85	100.18	.18	7.05	1.67	9.3	18.88	3.91	.207	3.25
6699	do	36-50	do	.09	16.10	101.11	.14	6.69	1.12	8.0	18.45	3.97	.215	3.25
6678	Kirvin fine sandy loam	0-12	Tyler, Tex	.15	13.28	99.87	.21	.05	2.52	12.0	7.58	2.75	.363	2.02
6679	do	12-24	do	.09	12.14	99.51	.14	.07	.82	5.8	7.39	2.28	.308	1.74
6680	do	24-51	do	.11	11.57	99.32	.11	.02	.35	3.2	8.81	2.42	.274	1.89
6681	do	51-63	do	.09	10.89	99.54	.09	.02	.24	2.7	10.61	2.48	.234	2.03
6682	do	63-75	do	.17	11.29	99.42	.07	.01	.26	3.7	6.84	2.47	.360	1.80
6718	Vernon fine sandy loam [1]	0-3	Guthrie, Okla	.19	18.05	100.43	.70	.06	8.55	12.2	11.40	3.45	.303	2.65
6719	do	3-10	do	.09	11.45	100.07	.21	.04	2.02	9.6	11.20	3.12	.279	2.44
6720	do	10-27	do	.08	10.62	99.87	.15	.02	.95	6.3	11.38	2.94	259	2.34
6721	do	27-58	do	.10	8.66	100.62	.10	.00	.25	2.5	13.07	2.88	.221	2.35
6797	Shelby silt loam [1]	0-7	Bethany, Mo	.14	16.34	100.73	.37	.05	5.96	16.1	13.22	3.31	.252	2.65
6798	do	8-12	do	.09	13.24	100.65	.19	.03	2.61	13.7	11.42	3.30	.262	2.62
6799	do	12-20	do	.12	11.51	100.93	.16	.01	2.07	12.9	11.18	3.28	.265	2.60
6800	do	20-24	do	.11	10.75	100.62	.11	.01	1.34	12.2	11.47	3.36	.293	2.60
6801	do	24-48	do	.10	9.75	100.14	.08	.17	.64	8.0	11.22	3.57	.319	2.71
6802	do	48-60	do	.10	9.74	100.52	.07	.40	.56	8.0	10.84	3.54	.326	2.67
6802A	Shelby silt loam (sand pocket)	4 ft.	do	.10	9.03	100.30	.07	.31	.61	8.7	11.30	3.07	.271	2.41
6802B	Shelby silt loam [1]	60-84	do	.09	9.03	100.62	.06	.43	.45	7.5	8.89	4.33	.487	2.91
6842	Colby silty clay loam	2-10	Hays, Kans	.14	13.41	100.05	.30	1.85	4.07	13.6	19.41	4.25	.230	3.45
6843	do	10-20	do	.13	13.69	100.02	.17	3.74	1.79	10.5	18.47	4.18	.227	3.41
6844	do	20-33	do	.11	12.03	100.38	.09	3.85	.62	6.9	18.55	4.29	.231	3.47
6845	do	33-47	do	.09	12.12	100.77	.09	4.65	.53	5.9	20.32	4.27	.210	3.52
6846	do	47-60	do	.09	11.57	99.98	.06	4.23	.23	3.8	19.39	4.38	.226	3.57
6847	do	60-72	do	.10	12.25	100.83	.06	5.11	.21	3.5	19.17	4.37	.228	3.56
6977	Cecil sandy clay loam	0-6	Statesville, N. C	.08	16.95	100.68	.15	.05	2.30	15.3	6.94	1.65	.238	1.34
6978	do	6-32	do	.04	14.25	99.91	.07	.04	.27	3.9	7.27	1.69	.233	1.28
6979	do	32-60	do	.04	12.94	100.28	.06	.06	.09	1.5	7.35	1.88	.256	1.43
8069	Palouse silt loam	0-20	Pullman, Wash	.15	13.36	100.74	.32	.04	3.81	11.9	10.92	3.23	.301	2.48
8070	do	20-33	do	.11	11.25	100.40	.15	.00	1.69	11.3	9.52	3.31	.350	2.45
8071	do	33-62	do	.09	10.86	100.18	.12	.00	1.00	8.3	10.02	3.25	.324	2.45
8072	do	62-75	do	.06	9.93	100.58	.09	.00	.52	5.8	10.15	3.45	.339	2.57
8073	do	75-84	do	.06	9.82	100.88	.10	.00	.52	5.2	10.21	3.50	.343	2.61
8736	Marshall silt loam	0-13	Clarinda, Iowa	.35	16.03	100.73	.36	.02	6.47	18.0	13.68	3.69	.270	2.91
8737	do	13-24	do	.29	14.28	100.36	.27	.01	4.81	17.8	13.45	3.66	.272	2.88
8738	do	24-45	do	.24	11.85	100.57	.19	.02	2.36	12.4	13.40	3.72	.278	2.91
8739	do	45-71	do	.24	11.18	99.81	.22	.01	2.57	11.7	13.65	3.57	.262	2.83

[1] Analyses of these soils are averages of duplicate samples.

Variations in the erosional behavior of the different layers of the Houston profile are obviously not due to variations in the type of colloid, and causes for such variation must be sought elsewhere. The colloidal content, as shown by the mechanical analyses, varies to some degree, though even in this respect Houston black clay is remarkably constant. It is apparent, therefore, that this soil, in contrast with others to be discussed later, has suffered but little translocation of colloidal material. The several soil layers show considerable variation in organic matter, and this is undoubtedly responsible for the inversion of relative amounts of colloid in the first two layers, as shown by the water-adsorption method. Taken collectively, with other minor variations, the differences in amount of organic matter and calcium carbonate produce a very evident variation in the profile when examined in the field. The change is most marked at a depth of about 36 inches. However, the general constancy of texture of the soil and composition of the colloid may be considered a fairly satisfactory explanation of the fact that, in this soil, erosion is for the most part of the variety known as sheet erosion. Sheet erosion appears to be charactertistic of other soils with uniform texture and colloid.

The erosion ratio given in Table 1 for the surface layer of Houston black clay, although low as compared with other soils, is still much higher than that for the layer lying below it. This lowering of the erosion ratio for the soil layer immediately below the surface soil is not confined to the Houston soil, but appears to be general in all soils. In the Houston soil the immediate cause is seen in the suspension percentage given in Table 1. The cause of this divergence, in turn, might be ascribed to the smaller quantity of colloidal carbonates in the surface soil. However, since the pH of the surface soil is the same as that of the layer immediately below it, there can scarcely be said to be a lower concentration of calcium ions; indeed, the greater quantity of organic matter would seem to call for an increased base content for the same pH.

It is a matter of observation that the surface part of the Houston soil, on drying, fractures into very small easily suspended particles, whereas the more slowly drying subsurface soil fractures into masses of larger size. The ease with which these small particles are transported or suspended presumably accounts for the high erosivity of the Houston soil, in spite of its low erosion ratio, and may account for differences in the suspension percentage. In this connection a laboratory observation is recorded. Whenever the thick suspension (from a Pasteur-Chamberland filter) of a series of colloids is evaporated to dryness on the steam bath, the tendency to fracture is most strikingly marked in those colloids of high organic matter. By application of this observation it is believed that the organic matter of the Houston soil is associated with the peculiar manner in which this soil disintegrates under field conditions. The physical effects of organic matter, the cementing properties of dissolved and reprecipitated calcium carbonate, together with the flocculating effect of the calcium ion, are held to be amply sufficient cause for the peculiar erosive characteristics of this soil.

Kirvin fine sandy loam offers in many respects a striking contrast to Houston clay in that the colloid content of the various horizons

is markedly variable. (Table 1.) The colloid composition is likewise unusually varied. The calcium, potassium, and phosphorus content of the colloid of the surface horizon are higher than in the B horizon colloid, differences which may be referred to the ash content of the vegetation. The pH value of the surface soil is correspondingly increased. The relative percentages are of course greatly modified in the whole soil by reason of the extreme textural changes in the various horizons. The manganese and organic matter are sharply concentrated in the colloid of horizon A. The combined water (ignition loss minus organic matter) of the colloid of the various horizons is approximately 11 per cent. The variations are roughly consistent with the variations in iron oxide content, as shown by the silica-iron oxide ratio. The silica-sesquioxide ratio when considered alone indicates a fair constancy of colloid composition. The average value of this ratio is 1.9, which approximates the theoretical value of 2.0 for kaolinite or halloysite. The iron oxide content is relatively high, and if the assumption is made that all the iron is present as free oxide, the silca-alumina ratio indicates a much higher silica content.

That the iron oxide content is at least partly free is indicated by the color of the organic-free colloid, which is bright red, and also by the change in the iron oxide-alumina ratio in the upper four strata. That free colloidal quartz is probably present in the colloid of the A horizon is indicated, though not proved, by the difference in the relative values of the iron oxide-alumina and the silica-iron oxide ratios, as well as by the slightly greater silica-alumina ratio in the surface horizon as compared with the second horizon. There has been no podzolization of the soils, and laterization, although indicated, has not progressed to any extent. In general, the relative changes in the various ratios tend to indicate an unrelated degree of weathering which may be the result of lateral leaching of the colloid. This is not improbable, in view of the marked changes in the texture of the different horizons of this soil.

Perhaps the most important inference to be drawn from the data for Kirvin fine sandy loam, as affecting erosion, is obtained through a consideration of the quantities of colloid fraction shown in the different layers. It is clear that the increase of colloid from 5.6 per cent in the 0 to 12 inch layer to 59.4 per cent in the 12 to 24 inch layer indicates removal of enormous quantities of colloid from the upper horizon, either by erosion or eluviation.

That the colloid percentage is highest in the B horizon shows clearly that eluviation has taken place. That the quantity of colloid so transferred is large is indicated by the decrease in colloid content as lower levels are reached. The effect of thus "sealing" the B horizon with colloid is not so marked in soils with colloids of low silica-sesquioxide ratio as in less weathered soil, but in a soil with so marked an alteration of texture as the Kirvin, the effect of this sealing on permeability must be great, and therefore must in turn affect the erosion of the surface soil.

Attention should also be called to the increased erosional characteristics of the lower strata of this soil as represented by the increase of very fine sand and decrease of colloid content. This is reflected in the increased erosion ratios of the lower layers. These in turn affect the character of erosional effects in flood periods when erosion

reaches the lower levels, with resultant gullying from the more rapid erosion of the deep-lying material. Gully formation in the Kirvin soil is strikingly marked.

Vernon fine sandy loam is similar to the Kirvin soil so far as the color of the organic-free colloid is concerned. There are, however, some very striking differences. The silica-alumina ratio is high, approaching that of unweathered soils. The base content and, by inference, the base-exchange capacity are also very greatly in excess of the usual values for red soils. Despite the red color of the colloid the iron content is not excessive, and its alteration in quantity relative to silica through the first 27 inches is but slight. Evidence of chemical fractionation of the colloid is shown by the alteration of the silica-alumina and iron oxide-alumina ratios. On the basis of the changes in composition shown by these ratios, such weathering as has occurred can not be classed as podzolic, and the high silica-alumina ratio precludes the possibility of extensive laterization.

The evidence of eluviation is not clearly marked, despite the marked increase of colloid in the B horizon, since in the C horizon the quantities of clay and colloid are equally great. The conclusion seems to be warranted that the relatively small quantity of colloid in the surface soil is due to a lateral selective erosion of the finer fractions of the soil. The coarser materials have eroded at a slower rate, but in summation the total erosion has been rather severe. In this connection it should be noted that this particular sample of Vernon soil does not contain a calcareous layer, although by reason of the general character and location of the soils of the Vernon series such a stratum would normally be present. In this soil, as in the Kirvin, gully formation is prevalent. The presence of a highly erosive substratum, as shown by the erosion ratio, again offers a satisfactory explanation of this type of erosion.

Shelby silt loam is a prairie soil, and the characteristics of its colloid are similar to those of the colloids derived from the Houston, Marshall, and Palouse soils, except that, unlike the Houston, it has only small quantities of carbonates which occur mainly in the colloids from the lower strata. Throughout the profile the colloids of this soil are very uniform, particularly in the upper 24 inches.[7] They have the usual characteristics which accompany a high silica-sesquioxide ratio, are easily dispersable in water, and have a high base content and base-exchange capacity. When free from organic matter the colloids are light gray, which indicates that the iron is not present in the form of hydrated oxide.

The high silica-alumina ratio indicates the relatively unweathered condition of the colloid, and no evidence of podzolization is found in the iron oxide-alumina ratios. The amount of colloid present in the surface layer is approximately half that of the second layer between depths of 8 and 12 inches, which in turn is greater than the amount to be found in the 24 to 48 inch layer. This is taken to mean that the strata between 8 and 24 inches have been enriched by illuviation, but the relative deficiency of colloid in the surface layer also indicates that the topsoil has lost a part of its colloid in

[7] In considering the relative values shown, it should also be noted that there is included in the profile the colloid (No. 6802A) obtained from a sand pocket. The inclusion of this sample indicates certain nonuniform conditions which are characteristic of the Shelby soil, but the sample is not properly a part of this particular profile.

the surface run-off water. The upward trend of the silica-alumina ratio at depths below 24 inches, together with a decreasing colloid content, serve to explain the increase with depth of the erosion ratio. This gradual increase of erosivity in the lower horizons results in the formation of broad U-shaped gullies when this soil is subjected to heavy rainfall. With more moderate rains, and by reason of its surface erosional characteristics, sheet erosion becomes prevalent in this type of soil.

Colby silt loam is a true chernozem, and its colloid possesses all the characteristics of this soil group. The colloid is practically constant in character throughout the profile and has the highest silica-sesquioxide and silica-alumina ratios of any of the soils covered in this investigation. The high values for these ratios are in accord with the results of the X-ray examination which showed the colloid to be of the montmorillonitic variety and in accord with the high base content of both colloid and soil. A summation of the evidence to be derived from the ratios of the major constituents shows markedly the unweathered condition of this soil. There is also only the slightest evidence of concentration of colloid in the second stratum at the expense of the surface soil. The differences in erosional characteristics shown by the different strata are not to be specifically ascribed to variations in the inorganic colloid or to alteration of textures, which are remarkably constant. The differences which do appear in the suspension percentage (Table 1) and in the moisture equivalent, which are reflected in the dispersion and erosion ratios, are to be attributed in part to alteration in structure. To what extent the structural differences are to be associated with the kind and quantity of organic matter is a question not answered by the data. Some of the differences between the surface layer and those beneath it are to be associated with differences in calcium carbonate content and to the slightly higher silt and lower clay content of the surface layer as compared with those of the soil immediately beneath it.

Cecil sandy clay loam is the only definitely lateritic soil on which an erosion station has been established. The silica-sesquioxide ratio is well below 1.5. If, however, we consider the silica-alumina ratio, it appears that if all free silica has been eliminated by solution, the degree of hydrolysis of the alumino-silica complex has not gone far beyond the halloysitic stage, the latter being assumed to have a ratio of 2. The lateritic characteristics of this soil may perhaps be attributed to its high content of iron oxide which is hydrated to a considerable degree, as shown by the difference between the ignition loss and the organic content.

The colloid is characterized by a low base content and base-exchange capacity and is in general typical of the series as determined by Holmes and Edgington (*10*). There is some indication of podzolization shown in the altering of the silica-iron oxide and iron oxide-alumina ratios, but the absence of a sample from the C horizon (below 60 inches) leaves some doubt as to the extent of podzolization of this particular profile. The transfer of colloidal material from the surface layer to lower strata, or its removal by erosion, is very marked, as shown by the percentages of this component which varies from 17.3 per cent in the 0 to 6 inch layer to

51.2 per cent in the 6 to 32 inch stratum. The percentage of colloid is nearly as high throughout the B horizon to a depth of 60 inches. From other samples of this same soil type, it is known that the C horizon is low in colloid.

Soils of this type are usually nonerosive in character, and this is indicated for the lower layers of this profile by the erosion ratios and also by the field data. The relative ease of erosion of the surface layer is due in large part to its low colloid content. The cultivation of corn and cotton on such a soil aggravates erosive conditions by destroying roots and leaf cover, which otherwise would bind and protect this noncoherent surface layer.

Palouse silt loam has the highest silt content of any of the station soils. When this is considered, along with the fact that it is not a weathered soil and that much of the area on which this soil is found is markedly rolling, it is realized that erosion is a serious problem despite the low rainfall of the region.

The silica-alumina ratio, as well as the X-ray examination, indicates that this soil has a colloid of the montmorillonitic type. The alteration of the silica-iron oxide and iron oxide-alumina ratios between the 0 to 20 inch and the 20 to 33 inch layers indicates that considerable podzolic effect accompanies whatever illuviation has taken place. The evidence of podzolization and the presence of as much as 24 per cent of colloid in the surface layers indicates that but little surface erosion has occurred in the profile sample. If such be the case, it would appear that the rainfall is so meager and at the same time so distributed that the natural grass cover of this soil type offers ample protection from the small run-off which occurs. However, the erosion ratio shows this soil to be decidedly erosive, and under cultivation severe erosion may be expected. The data from the station are not available to give a quantitative expression of this statement.

Marshall silt loam is a typical prairie soil and, as such, its colloid is characterized by uniformity throughout the profile. The silica-alumina ratio indicates a colloid of the montmorillonitic type and this is confirmed by the X-ray examination of this type reported by Hendricks and Fry (*9*), as well as by the examination made of this particular sample. As in Palouse silt loam, evidence of podzolization is slight but distinct; also, there is a large amount of colloid in the surface soil. Taken together they indicate the lack of surface erosion in this profile, owing no doubt to the excellent protection offered by the natural grass cover of the soil. Although not shown to be so erosive by the dispersion and erosion ratios, the character of this soil lends itself to easy erosion, as shown by the suspension percentage and by the percentage of total colloid extracted by centrifuging. The percentage of total colloid extracted is also high for other colloids of like type.

The erosion ratios which represent the Marshall profile are much more varied than might reasonably be anticipated in a soil so uniform in texture when so little variation in colloid is present. Chemically the most important differences in the profile are shown by the organic-matter percentage, both in the soil and in the colloid; yet the amounts bear no relative value to the suspension percentage or the

moisture equivalent, which, in turn, affect the dispersion and erosion ratios. The variations may be explained by attributing them in part to variations in soil structure, but this avoids rather than answers the question, unless causes are assigned to account for these structural differences. At present this can not be done. However, it is known that the erosion ratio is often lowest in the second soil layer and that usually this is in the zone of greatest compaction of the soil. In this respect Marshall silt loam is similar to the Houston, Shelby, and Colby soils included in this investigation. A decreasing amount of colloid in the two lower layers of the Marshall soil may, in the presence of a large percentage of silt, lower the cohesive property of the soil to an extent that would account for the increased erosivity of these strata. Whether these assumptions are correct or adequate the data at hand are not sufficient to determine. It will be of interest to learn from the field data, when assembled, whether the general relations indicated exist in fact.

PROPERTIES OF COMPOSITE PLOT SAMPLES

Composite samples of each tank plot at the erosion stations were obtained for the dual purpose of ascertaining the degree of uniformity of the soils over the area on which erosion data were to be collected and of furnishing a basis for comparison of such changes as may occur in these plots through varied cultural and other treatment. These samples were taken according to the following instructions:

> * * * A composite sample, aggregating at least 1 pound in weight, should be taken for each of the several soil layers through the vertical section of each plot, to a depth of 48 inches, wherever this depth is attainable. To make the composite sample, the sampling should begin 5 feet from the lower end of each plot (in the middle), and extend up the slope, at 10-foot intervals, to the rear (or upper) end of the plot. A soil auger or core sampler (King sampler) should be used for taking these, and the same amount of soil should be taken from each layer, thus making a thoroughly representative plot composite.

The samples were transferred to glass jars in this laboratory, and the material remaining from this study will be carefully preserved for comparison with samples to be taken in the future, in order that the changes caused by erosion may be determined.

Composite samples of Marshall silt loam, from Clarinda, Iowa, and of Palouse silt loam, from Pullman, Wash., have not been included in this study because of the recent installation of these stations. The samples from the six stations from which samples were received were subjected to the following determinations: Colloid by water-vapor adsorption, moisture equivalent, dispersion ratio, and complete mechanical analysis. From the results of these determinations the colloid (by water-vapor adsorption)-moisture equivalent ratio and the erosion ratio were calculated. The average value of each determination for all the plots (except desurfaced plots) at each station was computed for each horizon,[8] and the standard devi-

[8] In the following discussion and tables the term "horizon" is used to designate the horizon, or layer, represented by the sample, regardless of whether the soil exhibits true horizonal characteristics.

ation and the coefficient of variability [9] were calculated. The results of these determinations and calculations are shown in Table 4. For the purpose of comparison the same determinations on the profile samples as are shown in Table 1 are repeated.

The sites for the erosion stations were selected with great care, particularly in regard to securing a representative area of the soil type to be studied, and the location of the experimental plots on this area was carefully considered so that they would have as uniform slope and as uniform soil conditions as possible. The data in Table 4 show that, in general, the plots at each station are remarkably uniform in their characteristics. In many cases the differences between the value of the highest and the lowest determinations for any particular horizon are probably within the limits of experimental error. The greatest differences usually occur in the long or short plots,[10] indicating that the greatest variations in soil characteristics occur along, rather than across, the slope.

The short plots on the Cecil soil (No. 12), Kirvin (No. 1), and Vernon (No. 1) are noticeably at variance with the rest of the plots in several of their properties. The long plot on the Shelby soil was divided and sampled in two parts, and it may readily be noted that the upper half (which extends up the slope beyond the main body of the plots) is much heavier in texture and shows greater variation in its other properties than the rest of the plots.

The surface soil of the desurfaced [11] plots (listed in Table 4 as the second horizon) does not correspond to the second horizon in the Houston, Cecil, and Vernon soils, but in the others the agreement is quite close. This is no doubt due to the fact that the plot was not desurfaced to the same depth as the surface horizon of the profile sample.

The differences between the profile samples and the average values of the composite samples are greater than was expected. However, in most cases, the greatest differences can be ascribed to differences in depths of sampling. For example, the first horizon of the Cecil profile sample was taken to a depth of 6 inches, whereas the composite samples were taken to a depth of 7 inches. Since the B horizon of the Cecil soil is very heavy in texture, as compared with the A horizon, the greater depth of sampling included more of this material, resulting in much heavier texture for the composite samples than is normal for the A horizon.

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[9] The formulas used were standard deviation, $\sigma=\sqrt{\frac{\Sigma d^2}{n}}$, and coefficient of variability, $C=\frac{\sigma}{M}\times 100$, where d represents the deviation of each determination from the mean M. of the whole number of determinations n.

[10] The plots at all stations are 6 feet wide and the normal-length plots are 72.6 feet long, making an area of one one-hundredth of an acre. The short plots are 36.3 feet long (one two-hundredth of an acre) and the long plots are 145.2 feet long (one fiftieth of an acre).

[11] The surface soil of one or more plots at each station was removed to simulate a severely eroded condition and to compare the quantity of run-off and erosion with the normal surface condition.

TABLE 4.—*Analyses of composite samples by horizons from the erosion-station plots*

PHYSICAL PROPERTIES

Sample and location	Plot No.	Colloid by water-vapor adsorption in horizon—					Moisture equivalent in horizon—					Dispersion ratio in horizon—					Ratio of colloid to moisture equivalent in horizon—					Erosion ratio in horizon—				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*															
Houston black clay, Temple, Tex.	[1] P	41.1	40.2	35.6	26.7	-----	30.5	27.6	24.4	20.6	-----	10.9	5.4	6.7	10.1	-----	1.35	1.46	1.46	1.30	-----	8.1	3.7	4.6	7.8	-----
	1	38.6	39.2	34.1	25.8	24.0	29.7	31.2	27.9	24.3	22.6	12.5	14.9	15.9	20.0	20.8	1.30	1.26	1.22	1.06	1.06	9.6	11.8	13.0	18.8	19.6
	2	36.4	37.1	38.5	28.3	29.2	29.8	31.0	31.0	25.9	25.0	12.3	11.4	14.4	18.9	16.8	1.22	1.20	1.24	1.09	1.17	10.1	9.5	11.6	17.3	14.4
	3	38.6	40.8	34.6	27.9	24.0	30.8	31.0	28.0	26.0	23.4	9.7	13.5	14.6	17.6	22.1	1.25	1.32	1.24	1.07	1.03	7.8	10.2	11.8	16.4	21.4
	4	39.3	41.1	36.0	29.2	25.5	30.2	31.8	28.9	25.7	23.2	11.9	14.2	11.0	17.2	20.4	1.30	1.29	1.25	1.14	1.10	9.1	11.0	8.8	15.1	18.6
	5	40.2	38.4	32.7	20.4	25.1	30.5	30.0	27.1	24.6	23.4	9.2	12.2	15.1	18.2	18.6	1.32	1.28	1.21	1.07	1.07	7.0	9.5	12.5	17.0	17.4
	6	39.0	37.5	33.8	27.7	23.3	31.1	29.9	26.2	24.6	23.2	11.2	13.4	10.8	13.7	20.5	1.25	1.25	1.29	1.13	1.00	9.0	10.7	8.4	12.1	20.5
	7	39.8	38.1	31.4	27.6	24.2	29.2	29.6	25.5	24.3	21.9	9.6	12.8	14.6	21.1	19.5	1.36	1.29	1.23	1.14	1.10	7.1	9.9	11.9	18.5	17.7
	8	38.2	38.5	33.4	27.2	24.2	29.3	30.6	27.5	24.3	22.3	8.4	15.1	14.2	15.2	19.1	1.30	1.26	1.21	1.12	1.09	6.5	12.0	11.7	13.6	17.5
	9	39.0	39.1	32.5	25.0	23.4	30.1	30.2	26.2	22.9	22.7	13.4	14.9	16.1	15.7	19.6	1.30	1.29	1.24	1.09	1.03	10.3	11.5	13.0	14.4	19.0
	10	39.4	36.9	33.0	27.0	26.5	29.9	29.6	26.6	23.8	23.0	11.8	15.6	15.6	16.6	18.1	1.32	1.25	1.24	1.13	1.15	8.9	12.5	12.6	14.7	15.7
	[4] 11	-----	30.4	23.6	24.8	25.6	-----	24.0	24.5	23.0	22.7	-----	6.0	22.3	18.6	19.1	-----	1.27	1.96	1.08	1.13	-----	4.7	22.1	17.2	16.9
Average [5]	-----	38.9	38.7	34.0	27.2	24.9	30.1	30.5	27.5	24.6	23.1	11.0	13.8	14.2	17.4	19.6	1.29	1.27	1.24	1.10	1.08	8.5	10.9	11.5	15.8	18.2
Standard deviation	-----	1.0	1.4	1.9	1.2	1.7	.6	.7	1.5	.9	.8	1.6	1.3	1.8	2.1	1.4	.04	.03	.02	.03	.05	1.3	1.0	1.6	2.1	2.0
Coefficient of variability	-----	2.5	3.5	5.6	4.3	6.8	1.9	2.3	5.5	3.8	3.4	14.4	9.5	12.5	12.2	7.3	3.0	2.4	1.8	2.7	4.3	15.1	8.9	13.5	13.0	11.0
Cecil sandy clay loam, Statesville, N. C.	[1] P	20.0	45.7	50.0	-----	-----	20.0	26.6	28.7	-----	-----	22.4	11.2	9.6	-----	-----	1.00	1.72	1.74	-----	-----	22.4	6.5	5.5	-----	-----
	[4] 1	-----	42.0	51.7	-----	-----	-----	25.3	29.4	-----	-----	-----	15.4	10.6	-----	-----	-----	1.66	1.76	-----	-----	-----	9.3	6.0	-----	-----
	[4] 2	-----	38.8	49.4	-----	-----	-----	23.3	29.8	-----	-----	-----	16.7	9.8	-----	-----	-----	1.67	1.66	-----	-----	-----	10.0	5.9	-----	-----
	[4] 3	-----	43.0	53.1	-----	-----	-----	26.0	29.6	-----	-----	-----	14.3	10.9	-----	-----	-----	1.65	1.79	-----	-----	-----	8.7	6.1	-----	-----
	4	29.5	47.8	49.3	-----	-----	22.4	26.5	28.8	-----	-----	19.8	12.3	9.8	-----	-----	1.32	1.80	1.71	-----	-----	15.6	6.8	5.8	-----	-----
	5	27.4	47.7	49.8	-----	-----	22.5	27.1	30.0	-----	-----	20.8	12.1	9.7	-----	-----	1.22	1.76	1.66	-----	-----	17.1	6.9	5.9	-----	-----
	6	28.9	47.0	55.6	-----	-----	22.6	26.7	31.1	-----	-----	22.0	13.9	10.7	-----	-----	1.28	1.76	1.79	-----	-----	17.2	7.9	6.0	-----	-----
	7	32.2	48.9	57.9	-----	-----	23.1	28.0	32.4	-----	-----	21.6	11.7	8.3	-----	-----	1.39	1.75	1.79	-----	-----	15.5	6.7	4.7	-----	-----
	8	32.7	49.3	51.0	-----	-----	22.3	28.8	32.2	-----	-----	21.6	10.7	8.4	-----	-----	1.47	1.71	1.58	-----	-----	14.7	6.2	5.3	-----	-----
	9	30.4	51.2	57.8	-----	-----	23.1	29.4	32.0	-----	-----	17.6	8.7	8.2	-----	-----	1.32	1.74	1.81	-----	-----	13.4	5.0	4.5	-----	-----
	10	32.1	50.3	57.4	-----	-----	23.8	28.0	30.1	-----	-----	22.7	9.5	7.4	-----	-----	1.35	1.80	1.91	-----	-----	17.2	5.3	3.9	-----	-----
	[3] 11	29.7	47.2	51.3	-----	-----	21.8	26.7	29.2	-----	-----	19.4	9.3	9.5	-----	-----	1.36	1.77	1.76	-----	-----	14.3	5.2	5.4	-----	-----
	[2] 12	36.1	56.0	51.9	-----	-----	23.5	29.7	29.6	-----	-----	19.2	10.5	9.3	-----	-----	1.54	1.89	1.75	-----	-----	12.4	5.6	5.3	-----	-----
Average [5]	-----	31.0	49.5	52.6	-----	-----	22.8	27.9	30.6	-----	-----	20.5	11.0	9.0	-----	-----	1.36	1.78	1.75	-----	-----	15.2	6.2	5.2	-----	-----
Standard deviation	-----	2.4	2.7	3.5	-----	-----	.6	1.1	1.3	-----	-----	1.5	1.6	1.0	-----	-----	.09	.05	.09	-----	-----	1.6	.8	.4	-----	-----
Coefficient of variability	-----	7.7	5.4	6.7	-----	-----	2.6	4.1	4.2	-----	-----	7.5	14.6	10.8	-----	-----	6.8	2.8	5.1	-----	-----	10.7	13.5	8.5	-----	-----

Kirvin fine sandy loam, Tyler, Tex.	[1] P	5.9	56.6	49.5	32.8	10.0	7.9	30.5	28.5	21.2	6.7	37.2	13.3	12.4	16.6	24.9	0.75	1.86	1.74	1.55	1.49	49.6	7.2	7.1	10.7	16.7
	[2] 1	5.1	50.6	49.5	50.5	-----	7.8	31.1	30.0	31.7	-----	28.8	20.1	18.4	12.2	-----	.65	1.63	1.65	1.59	-----	44.3	11.2	11.2	7.7	-----
	[2] 2	6.7	60.9	62.0	48.0	-----	8.5	33.6	34.5	30.1	-----	31.2	19.8	15.7	16.6	-----	.79	1.81	1.80	1.59	-----	39.5	10.9	8.7	10.5	-----
	3	6.7	66.3	67.4	43.7	-----	8.4	37.0	36.5	30.2	-----	33.6	16.7	19.3	23.1	-----	.80	1.79	1.85	1.45	-----	42.0	9.3	10.4	15.9	-----
	4	6.1	63.6	58.5	43.8	-----	7.9	35.6	35.9	29.7	-----	33.3	23.9	23.3	21.0	-----	.77	1.79	1.63	1.47	-----	43.3	13.5	14.3	14.3	-----
	5	6.0	64.1	68.6	51.9	-----	8.0	35.9	37.3	30.5	-----	25.3	19.7	20.1	14.2	-----	.75	1.78	1.84	1.70	-----	33.7	11.1	10.9	8.3	-----
	6	6.1	69.7	59.4	49.6	-----	8.2	36.9	34.9	29.6	-----	29.7	20.4	21.2	21.3	-----	.74	1.89	1.70	1.68	-----	40.0	10.8	12.5	12.7	-----
	7	6.3	64.9	66.0	47.5	-----	8.3	37.0	36.2	30.5	-----	27.3	18.6	19.0	19.5	-----	.76	1.75	1.82	1.56	-----	35.9	10.6	10.4	12.5	-----
	8	6.7	66.5	61.1	47.9	-----	8.7	36.6	37.0	29.6	-----	22.0	18.7	16.4	18.3	-----	.77	1.82	1.65	1.62	-----	28.6	10.3	9.5	11.3	-----
	9	7.5	61.7	66.5	47.4	-----	8.6	35.6	37.3	30.2	-----	27.5	21.5	17.8	15.7	-----	.87	1.73	1.78	1.57	-----	31.6	12.4	10.0	10.0	-----
	[4] 10	-----	61.2	61.3	49.7	-----	-----	35.3	36.7	31.0	-----	-----	14.8	19.1	17.1	-----	-----	1.73	1.67	1.60	-----	-----	8.6	11.4	10.7	-----
	[4] 11	-----	62.3	53.7	46.4	-----	-----	35.0	32.7	29.2	-----	-----	15.2	17.2	19.6	-----	-----	1.78	1.64	1.59	-----	-----	8.5	10.5	12.3	-----
	[4] 12	-----	57.4	61.9	49.1	-----	-----	32.9	34.6	30.2	-----	-----	14.9	19.0	15.7	-----	-----	1.74	1.79	1.63	-----	-----	8.6	10.6	9.6	-----
Average [5]		-----	6.4	63.1	62.4	47.8	-----	8.3	35.5	35.5	30.2	-----	28.7	19.9	19.0	18.0	-----	.8	1.8	1.8	1.6	-----	37.7	11.1	10.9	11.5	-----
Standard deviation		-----	.6	5.4	5.7	2.6	-----	.3	1.9	2.2	.6	-----	3.5	1.9	2.2	3.3	-----	.06	.04	.08	.08	-----	5.2	1.1	1.6	2.5	-----
Coefficient of variability		-----	9.7	8.5	9.1	5.4	-----	3.6	5.2	6.1	2.1	-----	12.3	9.5	11.6	18.5	-----	7.1	2.4	4.4	5.0	-----	13.7	10.3	14.4	22.0	-----
Vernon fine sandy loam, Guthrie, Okla.	[1] P	7.4	8.3	21.5	19.4	-----	9.6	9.1	17.7	18.4	-----	23.3	17.2	16.6	25.7	-----	.77	.91	1.21	1.05	-----	29.9	18.9	13.7	24.5	-----
	[2] 1	5.2	6.2	20.7	18.4	-----	7.1	7.7	17.6	16.5	-----	41.8	26.9	28.2	38.2	-----	.73	.81	1.18	1.12	-----	57.3	45.6	23.9	34.1	-----
	[2] 2	7.0	7.8	20.1	16.5	-----	9.5	9.1	16.8	15.8	-----	33.0	26.9	20.9	27.2	-----	.74	.86	1.20	1.04	-----	44.6	31.3	17.4	26.1	-----
	3	6.4	7.9	19.3	18.9	-----	9.3	9.7	17.7	16.3	-----	32.3	24.1	24.6	23.4	-----	.69	.82	1.09	1.16	-----	46.8	29.4	22.6	20.1	-----
	4	7.6	8.7	21.5	18.7	-----	9.4	10.0	18.6	18.2	-----	32.7	35.0	26.7	28.6	-----	.81	.87	1.16	1.03	-----	40.3	40.3	23.0	27.7	-----
	5	6.4	8.1	22.5	20.2	-----	9.8	9.3	18.2	18.5	-----	40.7	36.5	26.4	25.0	-----	.65	.87	1.24	1.09	-----	62.6	42.0	21.3	22.9	-----
	6	7.4	8.4	17.0	16.8	-----	10.1	10.3	16.6	17.1	-----	36.1	29.5	26.1	25.5	-----	.73	.82	1.02	.98	-----	49.4	35.9	25.6	26.0	-----
	7	7.3	8.4	20.7	16.9	-----	10.5	8.7	18.6	16.5	-----	33.5	31.8	23.7	27.4	-----	.70	.97	1.11	1.02	-----	47.9	32.8	21.3	26.8	-----
	8	7.2	9.2	23.4	24.5	-----	10.5	11.7	19.7	19.7	-----	31.3	32.2	22.6	25.6	-----	.69	.79	1.19	1.24	-----	45.4	40.7	19.0	20.7	-----
	[4] 9	-----	13.4	21.8	19.3	-----	-----	13.3	19.7	18.2	-----	-----	23.1	21.3	29.4	-----	-----	1.01	1.11	1.06	-----	-----	22.9	19.2	27.7	-----
Average [5]		-----	6.8	8.1	20.7	18.9	-----	9.5	9.6	18.0	17.3	-----	35.2	31.6	24.9	27.6	-----	.72	.85	1.15	1.09	-----	49.3	37.3	21.8	25.6	-----
Standard deviation		-----	.7	.8	1.8	2.4	-----	1.0	1.1	1.0	1.1	-----	3.8	4.4	2.3	4.3	-----	.04	.05	.07	.08	-----	7.0	5.4	2.5	4.2	-----
Coefficient of variability		-----	10.9	10.2	8.9	12.9	-----	10.6	11.6	5.3	6.1	-----	10.7	13.9	9.0	15.5	-----	6.1	6.2	5.7	7.3	-----	14.2	14.5	11.3	16.4	-----
Shelby silt loam, Bethany, Mo.	[1] P	23.1	49.6	49.4	37.2	27.0	24.5	34.9	34.2	27.1	23.0	26.2	13.0	15.8	22.5	28.2	0.94	1.42	1.44	1.37	1.17	27.9	9.2	11.0	16.4	24.1
	[3] L1	24.7	40.3	46.9	36.2	-----	24.3	29.8	31.9	29.7	-----	25.4	23.7	26.3	30.3	-----	1.02	1.35	1.47	1.22	-----	24.9	17.5	17.9	24.8	-----
	[3] U1	27.1	29.9	37.6	46.8	-----	27.0	27.0	27.8	32.8	-----	28.3	22.3	20.1	31.3	-----	1.00	1.11	1.35	1.43	-----	28.3	20.1	22.3	21.9	-----
	2	25.0	45.3	41.7	44.7	-----	24.3	32.1	34.8	38.2	-----	30.7	18.9	23.5	27.9	-----	1.03	1.41	1.50	1.17	-----	29.8	13.4	19.6	23.8	-----
	3	24.3	37.9	48.5	35.0	-----	25.0	30.8	33.1	27.6	-----	26.6	23.2	23.8	29.8	-----	.97	1.23	1.46	1.27	-----	27.4	18.9	16.3	23.5	-----
	4	24.5	35.9	44.1	38.7	-----	24.7	27.2	30.1	31.1	-----	29.8	24.3	24.6	30.6	-----	.99	1.32	1.47	1.24	-----	30.1	18.4	16.7	24.7	-----
	5	26.1	32.5	46.6	30.8	-----	25.3	26.1	32.2	28.4	-----	27.4	23.9	26.3	30.0	-----	1.03	1.25	1.45	1.08	-----	26.6	19.1	18.2	33.8	-----
	6	26.0	45.8	47.5	39.9	-----	24.9	31.0	31.6	28.8	-----	27.8	21.7	23.0	30.1	-----	1.04	1.48	1.50	1.39	-----	26.7	17.4	15.3	21.6	-----
	7	25.1	44.8	43.3	40.2	-----	24.3	31.1	31.0	28.2	-----	26.1	24.7	22.6	28.6	-----	1.03	1.44	1.40	1.43	-----	25.3	17.1	16.2	20.0	-----
	8	27.5	48.6	43.2	41.5	-----	25.5	33.1	34.9	30.2	-----	26.7	20.2	25.0	29.6	-----	1.08	1.47	1.24	1.37	-----	24.7	13.7	20.1	21.6	-----
	9	25.8	45.8	45.8	37.7	-----	25.5	31.1	31.5	27.4	-----	26.9	21.2	21.3	32.0	-----	1.01	1.47	1.45	1.38	-----	26.6	14.4	14.7	23.2	-----
	[4] 10	-----	43.2	49.3	44.0	-----	-----	29.3	32.9	37.3	-----	-----	15.9	21.3	27.7	-----	-----	1.47	1.50	1.18	-----	-----	10.8	14.2	23.5	-----
Average [5]		-----	25.6	40.7	44.5	39.2	-----	25.1	29.9	31.9	30.2	-----	27.6	22.4	24.7	30.6	-----	1.02	1.35	1.40	1.30	-----	27.0	17.0	17.7	23.9	-----
Standard deviation		-----	1.0	6.2	3.2	4.4	-----	.8	2.2	2.0	3.1	-----	1.6	1.8	2.4	2.1	-----	.03	.11	.10	.11	-----	1.8	2.3	2.3	3.6	-----
Coefficient of variability		-----	4.0	15.3	7.2	11.3	-----	3.1	7.5	6.3	10.2	-----	5.7	8.0	9.5	6.9	-----	2.8	8.6	7.0	8.8	-----	6.7	13.2	12.7	15.1	-----

[1] Profile sample
[2] Short plot (one two-hundredths of an acre).
[3] Long plot (one-fiftieth of an acre).
[4] Desurfaced plot.
[5] Average does not include profile sample or desurfaced plots.
[7] Lower half of plot 1 (long plot).
[8] Upper half of plot 1 (long plot).

TABLE 4.—*Analyses of composite samples by horizons from the erosion-station plots*—Continued

PHYSICAL PROPERTIES—Continued

Sample and location	Plot No	Colloid by water-vapor adsorption in horizon—					Moisture equivalent in horizon—					Dispersion ratio in horizon—					Ratio of colloid to moisture equivalent in horizon—					Erosion ratio in horizon—				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*															
Colby silty clay loam, Hays, Kans.	[1] P	32.1	30.7	29.0	29.1	29.9	27.3	25.2	24.1	23.6	24.8	14.9	10.7	18.7	24.3	35.6	1.18	1.22	1.20	1.23	1.21	12.6	8.8	15.6	19.7	29.4
	[2] 1	29.3	29.7	27.7	24.3	.....	25.2	24.2	23.5	22.3	.....	22.7	20.5	26.0	31.9	.....	1.16	1.23	1.18	1.09	.....	19.6	16.7	22.0	29.3	.....
	[3] 2	32.0	29.6	27.1	27.1	.....	26.8	25.0	23.0	22.8	.....	18.6	19.8	22.4	26.7	.....	1.19	1.18	1.18	1.19	.....	15.7	16.8	19.0	22.5	.....
	3	30.6	28.7	26.5	26.3	.....	27.5	24.3	22.9	23.5	.....	19.9	19.8	27.0	33.8	.....	1.11	1.18	1.16	1.12	.....	17.9	16.7	23.3	30.2	.....
	4	31.6	30.1	27.5	28.9	.....	28.6	24.8	23.6	23.6	.....	18.4	22.5	26.5	34.5	.....	1.10	1.21	1.17	1.22	.....	16.7	18.6	22.7	28.2	.....
	5	31.9	30.0	27.4	28.0	.....	27.8	25.8	23.8	24.0	.....	19.5	23.0	30.1	33.2	.....	1.15	1.16	1.15	1.17	.....	16.8	19.8	26.1	28.4	.....
	6	31.1	29.4	28.6	28.8	.....	26.6	25.1	23.9	24.2	.....	20.5	22.2	29.5	34.4	.....	1.17	1.17	1.20	1.19	.....	17.5	19.0	24.5	28.9	.....
	7	30.1	28.9	27.7	26.3	.....	26.5	25.1	23.5	23.0	.....	19.0	21.7	31.4	31.3	.....	1.14	1.15	1.18	1.14	.....	16.7	18.9	26.6	27.5	.....
	8	30.3	26.1	26.7	26.6	.....	26.4	24.3	25.2	24.8	.....	18.8	21.3	25.0	32.3	.....	1.15	1.07	1.05	1.07	.....	16.3	19.9	23.5	30.2	.....
	9	29.9	27.7	26.2	26.6	.....	28.2	25.8	23.8	25.2	.....	17.5	22.9	32.0	32.1	.....	1.06	1.07	1.10	1.06	.....	16.6	21.4	29.1	30.3	.....
	[4] 10	.....	26.7	27.7	27.6	27.8	.....	25.2	23.9	24.3	25.0	.....	25.5	28.3	35.6	35.4	.....	1.05	1.16	1.14	1.11	.....	24.1	24.4	31.2	31.9
Average [5]	.....	30.8	28.9	27.3	27.0	.....	27.1	24.9	23.7	23.7	.....	19.4	21.5	27.8	32.2	.....	1.14	1.16	1.15	1.14	.....	17.1	18.6	24.1	28.4	.....
Standard deviation	.....	.9	1.2	.7	1.4	.....	1.0	.6	.6	.9	.....	1.4	1.2	3.0	2.2	.....	.04	.05	.04	.05	.....	1.1	1.6	2.8	2.3	.....
Coefficient of variability	.....	2.9	4.2	2.6	5.0	.....	3.7	2.3	2.7	4.0	.....	7.3	5.5	10.8	6.9	.....	3.3	4.5	3.7	4.7	.....	6.3	8.3	11.5	8.0	.....

MECHANICAL ANALYSIS[6]

Sample and location	Plot No.	Sand in horizon—					Silt in horizon—					Clay in horizon—					Colloid <0.002 mm in horizon—					Organic matter by H_2O_2 in horizon—				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Houston black clay, Temple, Tex.	[1] P	10.9	9.6	10.5	14.0	----	23.0	25.1	27.0	31.0	----	60.4	64.1	61.8	54.6	----	44.9	46.6	44.1	36.2	----					
	[2] 1	11.1	9.7	9.9	13.9	16.5	23.9	23.5	25.1	30.4	28.3	62.9	62.9	64.0	55.3	54.9	44.2	45.0	40.7	35.5	33.3	1.8	0.5	0.7	0.2	0.1
	[3] 2	9.3	8.4	7.5	8.2	8.4	27.5	24.6	24.9	28.8	27.0	62.0	65.0	66.1	64.3	64.4	44.7	45.2	44.9	40.0	40.7	.8	1.5	1.2	.5	.1
	3	9.5	7.6	8.6	9.9	14.2	26.6	24.3	27.3	30.4	31.2	62.2	66.8	63.6	59.2	54.2	45.4	46.4	42.4	38.8	34.9	1.2	.8	.4	.4	.2
	4	9.7	8.4	8.9	9.6	14.4	25.9	24.8	25.3	27.4	29.6	62.6	66.4	65.2	62.8	55.8	45.4	47.9	45.0	41.1	35.7	1.3	.3	.3	0	.1
	5	9.3	8.7	9.0	9.5	10.1	24.9	25.1	25.6	29.4	30.5	64.8	65.4	63.8	60.6	59.0	48.4	46.4	42.6	37.5	40.2	.8	.6	.2	.2	.2
	6	10.9	7.6	8.4	10.0	12.5	25.2	23.7	23.7	29.0	29.1	63.6	67.9	64.4	60.6	57.8	45.7	47.0	42.4	38.8	34.3	1.0	.4	.3	.3	.3
	7	9.3	7.2	9.2	9.2	13.0	25.3	24.3	27.0	28.2	29.9	64.8	67.7	63.4	62.4	56.8	46.3	45.5	40.5	39.7	35.3	.3	.7	.3	0	0
	8	8.8	8.0	7.5	8.2	10.7	24.7	25.2	26.2	28.2	29.2	65.7	66.4	66.1	63.4	59.8	46.0	45.9	43.5	39.8	36.8	.3	.1	0	0	0
	9	9.6	7.3	9.0	11.6	10.6	25.1	24.9	26.8	28.5	29.0	64.6	67.6	63.9	59.6	60.1	45.2	46.0	40.9	36.7	37.9	.3	0	.2	0	0
	10	9.1	8.8	7.6	7.7	8.8	29.8	24.5	24.2	28.0	29.2	69.8	66.3	67.3	63.6	62.0	47.0	47.2	43.4	40.1	40.3	0	.1	.6	.4	0
	[4] 11	----	8.1	8.4	9.3	8.9	----	25.8	28.2	28.3	28.9	----	64.8	63.2	62.2	62.0	----	37.3	38.2	38.3	40.2	----	.1	0	0	0
Average [5]		----	9.7	8.2	8.6	9.8	11.9	25.0	24.8	26.0	28.6	29.3	64.3	66.2	64.8	61.2	58.5	45.8	46.3	42.6	38.8	36.9	.8	.5	.4	.2	.1
Standard deviation		----	.7	.7	.8	1.7	2.5	1.7	.7	1.0	1.1	1.1	2.2	1.4	1.1	2.6	3.1	1.1	.9	1.5	1.7	2.6	.5	.4	.3	.2	.1
Coefficient of variability		----	7.3	9.0	9.0	17.7	21.0	6.8	2.9	3.8	3.9	3.7	3.4	2.2	1.6	4.2	5.2	2.5	2.0	3.6	4.3	6.9	66.2	84.0	80.0	90.0	100.0
Cecil sandy clay loam, Statesville, N. C.	[1] P	53.1	30.8	23.1	----	----	20.7	12.1	17.1	----	----	26.2	57.1	59.8	----	----	17.8	51.6	48.6	----	----	----	----	----	----	----
	[4] 1	----	33.2	24.8	----	----	----	13.4	14.2	----	----	----	53.0	60.8	----	----	----	47.0	53.4	----	----	----	.2	0	----	----
	[4] 2	----	34.6	23.3	----	----	----	14.8	14.2	----	----	----	50.2	62.2	----	----	----	44.1	55.1	----	----	----	.2	0	----	----
	[4] 3	----	31.8	24.2	----	----	----	10.4	11.1	----	----	----	57.0	64.6	----	----	----	52.8	58.9	----	----	----	.4	0	----	----
	4	40.3	29.2	26.5	----	----	12.9	9.6	10.9	----	----	45.8	60.8	62.6	----	----	40.7	57.2	57.2	----	----	.7	.1	0	----	----
	5	42.8	29.4	26.3	----	----	14.7	9.9	10.9	----	----	40.9	60.4	62.7	----	----	36.1	55.7	57.7	----	----	1.1	0	0	----	----
	6	42.9	30.9	23.3	----	----	10.4	8.6	13.6	----	----	46.1	60.3	62.8	----	----	40.4	48.2	57.0	----	----	.3	0	0	----	----
	7	41.6	29.0	20.1	----	----	11.6	12.5	15.1	----	----	45.8	58.1	64.6	----	----	41.0	53.8	59.2	----	----	.8	.2	0	----	----
	8	41.1	28.0	22.6	----	----	12.4	12.6	14.8	----	----	45.6	59.0	62.6	----	----	39.6	54.0	56.3	----	----	.6	.1	0	----	----
	9	40.7	26.2	21.9	----	----	17.3	12.2	17.5	----	----	40.7	61.2	60.4	----	----	34.4	55.0	53.8	----	----	.8	.3	0	----	----
	10	40.0	29.3	23.4	----	----	18.2	14.0	22.2	----	----	41.2	56.2	54.2	----	----	35.2	51.0	48.8	----	----	.4	.3	.1	----	----
	[3] 11	41.3	29.8	27.5	----	----	20.5	14.6	18.6	----	----	37.9	55.2	53.6	----	----	32.0	49.3	46.6	----	----	.2	.1	0	----	----
	[3] 12	37.5	25.6	25.2	----	----	9.9	15.3	20.3	----	----	51.3	58.8	54.4	----	----	44.3	52.2	45.5	----	----	.9	0	0	----	----
Average [5]		----	40.9	28.6	24.1	----	----	14.2	12.1	16.0	----	----	43.9	58.9	59.8	----	----	38.2	52.9	53.6	----	----	.6	.1	----	----	----
Standard deviation		----	1.5	1.6	2.3	----	----	3.5	2.2	3.6	----	----	3.8	2.0	4.2	----	----	3.7	2.8	4.9	----	----	.28	.12	----	----	----
Coefficient of variability		----	3.7	5.7	9.5	----	----	24.6	18.2	22.5	----	----	8.7	3.3	7.0	----	----	9.7	5.4	9.2	----	----	46.7	120.0	----	----	----

[1] Profile sample.
[2] Short plot (one two-hundredths of an acre).
[3] Long plot (one-fiftieth of an acre).
[4] Desurfaced plot.
[5] Average dose not include profile sample or desurfaced plots.
[6] Determinations by L. T. Alexander, H. W. Lakin, and T. M. Shaw.

TABLE 4.—*Analyses of composite samples by horizons from the erosion-station plots*—Continued

MECHANICAL ANALYSIS—Continued

Sample and location	Plot No.	Sand in horizon—					Silt in horizon—					Clay in horizon—					Colloid <0.002 mm in horizon—					Organic matter by H_2O_2 in horizon—				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	3	3	4	5	1	2	3	4	5
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Kirvin fine sandy loam, Tyler, Tex.	[1] P	75.8	31.1	36.9	51.3	87.9	15.7	7.4	9.6	13.2	2.8	8.6	61.5	53.4	35.4	9.2	5.7	59.9	50.0	32.3	7.3	.....	.....	.....	.....	.....
	2 1	77.5	33.3	36.9	32.1	.....	14.3	10.3	9.9	12.1	.....	7.4	55.7	52.6	55.6	.....	5.9	54.4	50.3	52.4	.....	.5	.6	.4	0	.....
	3 2	76.3	29.1	26.4	35.9	.....	13.8	7.9	10.8	12.3	.....	9.4	62.6	62.8	51.6	.....	7.2	60.1	60.4	48.4	.....	.4	.4	0	0	.....
	3	76.1	22.0	19.1	30.3	.....	15.4	8.6	13.8	13.5	.....	7.7	68.0	66.6	55.6	.....	5.5	65.9	63.5	48.7	.....	.4	.9	.4	.3	.....
	4	76.2	23.6	20.6	28.0	.....	15.2	8.5	12.6	18.7	.....	7.8	66.8	66.2	53.0	.....	5.9	64.2	64.3	49.7	.....	.4	.8	.1	0	.....
	5	76.0	22.8	20.2	31.6	.....	14.7	8.1	11.8	15.7	.....	8.5	68.3	67.4	52.4	.....	7.2	67.0	66.5	49.8	.....	.7	.6	.4	0	.....
	6	76.8	22.1	23.5	31.5	.....	13.8	8.1	13.2	16.9	.....	8.7	69.4	63.0	51.5	.....	6.4	66.9	59.4	47.7	.....	.6	.3	0	0	.....
	7	78.3	21.5	23.2	30.8	.....	12.0	7.9	10.5	16.5	.....	8.4	69.4	65.6	52.4	.....	6.6	66.8	60.9	48.5	.....	1.0	.8	.5	.3	.....
	8	76.8	22.8	20.8	31.0	.....	12.5	6.2	10.2	17.0	.....	9.6	70.1	68.4	51.6	.....	7.0	67.6	64.8	48.1	.....	.8	.9	.5	.3	.....
	9	79.2	24.9	19.7	31.3	.....	10.7	7.6	11.1	16.5	.....	9.3	66.4	68.4	52.1	.....	7.6	64.6	65.4	49.0	.....	.8	.9	.6	0	.....
	[4] 10	.....	24.9	22.7	26.4	.....	.....	6.3	12.4	18.7	.....	.....	67.9	64.6	54.4	.....	.....	65.6	61.6	50.3	.....	.....	.6	.2	.2	.....
	[4] 11	.....	24.2	20.8	31.8	.....	.....	7.2	11.9	18.0	.....	.....	67.9	66.8	50.1	.....	.....	65.0	54.2	45.8	.....	.....	.5	.2	0	.....
	12	.....	28.9	25.1	28.6	.....	.....	7.8	9.9	17.4	.....	.....	62.4	64.2	53.7	.....	.....	59.7	60.4	49.3	.....	.....	.7	.3	.1	.....
Average [5]		.....	77.0	24.7	23.4	31.4	.....	13.6	8.1	11.5	15.5	.....	8.5	66.3	64.6	52.9	.....	6.6	64.2	61.7	49.1	.....	.6	.7	.3	.1	.....
Standard deviation		.....	1.0	3.7	5.3	2.0	.....	1.5	1.0	1.3	2.2	.....	.8	4.3	5.3	1.5	.....	.7	4.1	4.6	1.3	.....	.2	.2	.2	.12	.....
Coefficient of variability		.....	1.4	15.1	22.4	6.2	.....	10.9	12.5	11.4	14.0	.....	8.8	6.5	8.5	2.9	.....	10.3	6.3	7.5	2.7	.....	35.0	30.0	70.0	.....	.....
Vernon fine sandy loam, Guthrie, Okla.	[3] P	73.3	74.8	60.3	32.3	.....	18.5	13.0	12.4	35.1	.....	8.1	12.1	27.2	32.5	.....	5.3	10.0	24.0	27.6	.....	.....	.....	.....	.....	.....
	2 1	76.0	77.8	62.2	57.8	.....	16.0	12.1	12.5	18.4	.....	7.6	9.7	25.0	23.4	.....	5.6	8.1	23.3	20.5	.....	.7	.2	.1	.1	.....
	3 2	72.9	76.6	61.7	60.7	.....	17.0	12.3	12.6	15.7	.....	9.0	10.7	25.3	23.2	.....	6.7	9.4	23.1	19.5	.....	.9	.3	.2	.1	.....
	3	73.1	75.5	59.8	48.1	.....	17.0	12.5	12.4	25.0	.....	8.5	11.4	27.2	26.5	.....	6.7	9.5	23.4	21.2	.....	1.0	.4	.4	.1	.....
	4	72.9	74.2	53.9	40.0	.....	16.1	12.2	16.6	31.1	.....	9.8	13.0	28.9	28.5	.....	7.6	10.9	24.7	23.2	.....	1.0	.5	.4	.2	.....
	5	74.0	74.8	50.7	44.3	.....	15.8	12.7	17.0	23.8	.....	8.8	12.0	32.0	31.7	.....	6.6	9.6	27.3	26.1	.....	1.1	.4	.1	0	.....
	6	71.8	72.4	60.4	53.6	.....	16.8	14.2	15.0	20.4	.....	10.0	12.7	24.4	25.8	.....	8.1	10.8	21.0	19.5	.....	1.2	.6	0	.1	.....
	7	71.5	72.5	46.9	52.4	.....	17.1	16.6	23.7	24.9	.....	9.9	10.1	29.1	22.5	.....	7.9	9.0	18.4	24.3	.....	1.4	.5	0	0	.....
	8	70.5	74.0	41.2	32.4	.....	19.2	7.7	25.3	27.7	.....	9.1	17.7	32.8	39.5	.....	7.5	13.0	27.7	32.6	.....	1.0	.4	.5	.4	.....
	[4] 9	.....	65.8	36.2	37.6	.....	.....	14.9	30.0	32.1	.....	.....	18.6	33.3	29.9	.....	.....	16.2	26.3	24.2	.....	.....	.5	.3	.2	.....
Average [5]		.....	72.8	74.7	54.6	48.7	.....	16.9	12.5	16.9	23.4	.....	9.0	12.2	28.1	27.6	.....	7.1	10.0	23.6	23.4	.....	1.0	.4	.2	.1	.....
Standard deviation		.....	1.6	1.8	7.3	8.9	.....	1.0	2.3	4.7	4.7	.....	.9	2.4	3.0	5.3	.....	.8	1.4	2.9	4.2	.....	.2	.12	.18	.12	.....
Coefficient of variability		.....	2.2	2.4	13.3	18.2	.....	5.9	18.6	27.9	20.0	.....	10.2	19.3	10.6	19.3	.....	11.0	14.1	12.2	17.9	.....	20.0	30.0	90.0	120.0	.....

Shelby silt loam, Bethany, Mo.	[1] P	26.0	19.4	20.4	31.2	35.1	46.0	27.7	28.9	27.0	28.4	27.9	52.9	50.8	41.9	36.6	25.1	49.7	46.0	37.9	29.8				
	[7] L 1	23.8	21.1	20.6	31.6		45.9	36.0	32.6	28.0		26.5	40.5	45.6	40.0		22.1	36.7	41.0	34.9		3.5	1.8	1.0	.3	
	[8] U 1	13.3	17.2	20.6	22.1		52.2	47.5	38.5	32.2		29.6	32.7	39.4	44.8		24.1	27.4	33.8	40.6		4.3	2.1	1.1	.6	
	2	24.8	19.5	24.6	28.4		45.2	31.4	28.4	26.4		25.6	47.2	48.6	44.9		20.9	42.1	40.6	39.7		3.8	1.5	.1	.1	
	3	23.8	20.9	21.5	31.8		43.9	34.3	29.0	27.5		28.9	42.6	48.7	40.6		22.9	36.3	43.0	34.3		3.3	1.8	.6	0	
	4	24.9	23.4	25.3	31.0		42.9	37.7	28.4	27.3		27.6	36.0	45.2	41.0		22.0	32.1	40.8	35.0		3.8	2.5	.9	.4	
	5	23.4	23.2	24.1	34.4		44.6	40.3	27.8	27.1		27.4	32.9	46.7	38.0		23.2	29.0	41.9	31.3		4.1	3.1	1.0	.3	
	6	23.1	20.7	24.8	31.6		44.5	33.0	30.2	28.9		28.2	44.2	43.9	39.0		24.5	42.2	40.8	34.4		3.6	1.7	.8	.3	
	7	22.5	20.7	25.4	32.9		47.1	31.7	18.9	26.3		25.6	45.2	54.4	40.1		22.5	40.6	39.6	34.0		4.1	2.1	.9	.6	
	8	21.8	20.2	27.3	28.3		46.6	31.6	24.0	29.8		26.8	46.3	48.1	40.5		24.4	44.4	40.2	36.7		4.0	1.4	.2	1.0	
	9	23.0	24.1	19.3	31.2		46.8	27.0	33.5	27.6		26.6	46.8	46.2	41.0		23.3	43.0	42.7	34.7		3.0	1.6	.6	0	
	[4] 10		19.9	22.0	27.6			36.1	28.6	27.8			41.9	47.5	44.1			39.2	44.3	39.4			1.8	1.4	.3	
Average [5]			22.4	21.1	23.4	30.3		46.0	35.1	29.1	28.1		27.3	41.4	46.7	41.0		23.0	37.4	40.4	35.6		3.7	2.0	.7	.4	
Standard deviation			3.2	1.9	2.5	3.2		2.4	5.4	5.0	1.7		1.3	5.4	3.7	2.1		1.1	5.8	2.4	2.6		.4	.5	.3	.3	
Coefficient of variability			14.2	9.2	10.7	10.7		5.3	15.4	17.3	6.0		4.7	13.0	7.8	5.2		4.9	15.5	6.0	7.4		11.6	24.5	47.1	75.0	
Colby silty clay loam, Hays, Kans.	[1] P	18.5	18.8	13.9	13.8	10.6	46.5	42.8	47.2	47.8	51.0	35.0	38.5	38.9	38.3	38.4	31.0	32.8	30.4	28.7	29.1					
	[2] 1	17.6	15.4	15.0	17.7		47.3	45.2	46.8	46.9		33.2	38.8	38.0	35.2		28.7	29.3	28.3	25.1		1.4	.3	0	0	
	[3] 2	18.3	16.8	15.6	12.8		45.7	44.6	47.7	50.5		34.5	37.6	35.9	36.1		27.9	28.8	27.0	26.0		.9	.5	0	.1	
	3	15.6	15.9	15.4	16.1		47.0	45.8	46.8	47.7		34.9	37.5	37.0	35.5		27.7	28.5	27.0	26.0		1.7	.6	.5	.3	
	4	14.0	16.1	17.6	18.9		48.5	44.5	46.3	43.4		33.8	38.7	35.7	37.6		26.3	30.0	27.6	28.9		2.9	.4	0	0	
	5	15.4	19.1	18.9	16.0		48.4	41.7	44.0	48.3		34.3	38.6	36.9	35.5		29.5	30.5	28.0	28.1		1.5	.4	0	0	
	6	16.5	15.2	15.9	13.7		47.3	46.5	49.1	50.4		34.4	37.2	34.5	35.6		28.5	28.1	25.8	26.5		1.5	.6	.1	.1	
	7	18.2	16.0	17.1	16.0		45.1	44.0	46.7	49.3		34.5	38.6	35.2	33.9		27.1	28.5	25.8	25.1		1.7	1.0	.5	.4	
	8	16.6	14.8	13.3	15.1		47.2	47.8	49.4	49.1		33.8	36.5	36.4	34.9		26.9	27.8	27.2	28.3		1.8	.7	.6	.5	
	9	14.5	13.6	14.2	14.2		52.4	47.9	51.5	49.1		31.1	38.2	34.0	36.4		26.7	27.4	25.1	26.9		.8	0	0	0	
	[4] 10		15.0	13.5	14.4	13.9		47.7	50.4	51.0	50.6		37.1	36.0	34.5	35.2		27.8	27.6	26.8	26.5		0	0	0	0
Average [5]			16.3	15.9	15.9	15.6		47.7	45.3	47.6	48.3		33.8	38.0	36.0	35.6		27.7	28.8	26.9	26.8		1.6	.5			
Standard deviation			1.5	1.4	1.6	1.8		2.0	1.8	2.0			1.1	.8	1.2	1.0		1.0	1.0	1.0	1.3		.6	.3			
Coefficient of variability			9.0	9.0	10.3	11.6		4.1	4.1	4.3	4.2		3.2	2.0	3.3	2.7		3.6	3.3	3.8	4.9		35.6	54.0			

[1] Profile sample.
[2] Short plot (one two-hundredths of an acre).
[3] Long plot (one-fiftieth of an acre).
[4] Desurfaced plot.
[5] Average does not include profile sample or desurfaced plots.
[7] Lower half of plot 1 (long plot).
[8] Upper half of plot 1 (long plot).

Some differences may be noted in the dispersion and erosion ratios between the profile samples and the composite samples. The composite samples agree very well with each other, and several determinations made on the profile samples at various times are in close agreement. The reason for these discrepancies has not yet been definitely ascertained. It is believed to be due to structural variations resulting from seasonal differences in the taking of the samples.

The coefficients of variability are low in nearly all cases, indicating a high degree of uniformity. In order that the variability of the different soils might be compared, the average value of the coefficient was computed for all determinations, with the exception of the organic-matter determination, for each horizon of each soil. The results are shown in Table 5.

TABLE 5.—*Average*[1] *coefficients of variability of composite plot samples*

Horizon	Houston black clay	Cecil sandy clay loam	Kirvin fine sandy loam	Vernon fine sandy loam	Shelby silt loam	Colby silty clay loam
1	6.3	9.1	8.6	9.1	5.7	4.8
2	4.7	8.1	8.5	12.3	11.8	4.8
3	6.4	9.3	10.6	11.6	9.4	5.6
4	7.3		8.8	14.8	9.1	5.8
5	7.7					
Average	6.5	8.8	9.1	11.9	9.0	5.2

[1] Coefficients of variability for organic matter are not included.

These results indicate that the second horizon of the Houston soil is the most uniform and the fourth horizon of the Vernon the least uniform. However, the average of all horizons shows the Colby to have the most uniform profile and the Vernon, the least uniform. These figures correspond very closely to the results obtained by Holmes and Edgington (*10*) on the colloids from the Leonardtown, Miami, Chester, and Cecil soils.

Although it is obviously undesirable to make complete chemical analyses of the soil and colloid of the whole series of composite samples because of their great number, it seemed desirable to select a pair of the Houston composite samples which showed wide variation in physical properties in order to determine to what extent this variation is reflected by the chemical composition. In the Cecil composites, two plots showed very similar physical properties, and they were analyzed in order to determine to what extent this uniformity was reflected by the chemical composition. To these were added a pair of the samples from the desurfaced plots. It is to be expected that erosion will alter these more than the surface soils. The analyses are therefore available for comparison with future samples from the same plots. The results of these analyses are given in Table 6.

TABLE 6.—*Chemical composition of selected composite plot samples*[1]

Station	Soil type	Plot No.	Horizon	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO
				P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Temple, Tex.	Houston black clay.	[2] 2	3	22.94	0.37	2.68	5.97	0.05	33.58	0.98
				(66.78)	(1.08)	(7.80)	(17.38)	(.15)		(2.85)
		7	3	18.18	.34	2.42	4.91	.04	37.00	.84
				(65.02)	(1.22)	(8.66)	(17.56)	(.14)		(3.00)
Statesville, N. C.	Cecil sandy clay loam.	6	1	69.39	1.31	5.65	14.48	.29	.30	.08
		7	1	68.37	1.29	5.95	15.28	.32	.20	.06
		1	[4] 2	60.90	1.47	8.49	19.43	.09	.43	.85
		2	[4] 2	60.96	1.65	8.73	19.24	.11	.29	1.02

Station	Soil type	Plot No.	Horizon	K_2O	Na_2O	P_2O_5	SO_3	Loss on ignition	N_2	CO_2 from carbonates	H_2O at at 110° C.
				P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Temple, Tex.	Houston black clay.	[2] 2	3	0.65	0.29	0.30	0.12	31.94	0.14	26.99	4.60
				(1.89)	(.84)	(.87)	(.35)				
		7	3	.50	.21	.28	.24	34.89	.08	29.94	4.15
				(1.79)	(.75)	(1.00)	(.86)				
Statesville, N. C.	Cecil sandy clay loam.	6	1	.56	[3]	.08	.15	7.95	.09	.00	1.56
		7	1	.56	[3]	.07	.19	8.00	.08	.00	1.61
		1	[4] 2	.61	.04	.14	.23	7.07	.04	.00	1.94
		2	[4] 2	.45	.10	.17	.09	7.07	.05	.00	1.92

[1] Determinations by J. G. Smith and G. Edgington.
[2] Long plot (one-fiftieth of an acre).
[3] Trace.
[4] Surface of desurfaced plot.

[Figures in parentheses are for analyses calculated on carbonate-free basis]

The third horizon of plot 2 (long plot) and plot 7 on Houston black clay are unusual in that the colloid by water adsorption, the moisture equivalent, and the clay and colloid by mechanical analysis are the highest and the lowest, respectively, of any of the plots in this horizon. The chemical analyses reveal considerable differences in the various constituents, particularly CaO, but when the analyses are recalculated on the carbonate-free basis (figures in parentheses) the results are practically identical. This indicates that the properties of the third horizon of plot 7 are lower, owing to the greater dilution with $CaCO_3$.

The physical properties of the surface horizons of plots 6 and 7 on the Cecil soil are practically identical, except for the colloid by water-vapor adsorption and the organic matter by H_2O_2, which are higher in the latter. The chemical analyses indicate that there is a little more silica and less iron and alumina in the former, the rest of the constituents being almost uniform.

The analyses of the first two desurfaced plots of the Cecil soil reveal them to be practically identical in composition. The physical analyses indicate that plot 1 is slightly heavier in texture, but the slight differences are not reflected in the chemical analyses.

RUN-OFF AND EROSION DATA

Only four of the eight erosion stations were established in time to secure any run-off and erosion data during 1930. Of these, the stations at Guthrie, Okla., Hays, Kans., and Temple, Tex., were in operation during the entire year. The station at Tyler, Tex., was

in operation only during the latter part of the year. The year 1930 was unusual in many respects and was particularly notable on account of the unprecedented drought in practically all sections of the country. The station at Tyler reported no rain producing run-off from June to October. At Temple there was no run-off from May 23 to August 25. However, the stations at Temple and Hays each had a total rainfall for the year within a quarter of an inch of the normal, and the station at Guthrie had 0.61 inch more than the normal. This condition was brought about by unusually heavy rains in the spring and fall. The run-off and erosion data for each plot, together with the erosion ratio of the surface soil as shown in Table 4, are given in Tables 7, 8, 9, and 10.

TABLE 7.—*Run-off and erosion data from Temple, Tex., erosion station, 1930*

[Total rainfall, 33.01 inches; Houston black clay; slope, 3.75 per cent]

Plot No.	Erosion ratio	Run-off	Erosion	Erosion per inch of run-off	Treatment
		Per cent	*Tons per acre*	*Tons per acre*	
1 [1]	9.6	16.45	20.88	3.8	Cotton.
2 [2]	10.1	18.45	14.67	2.4	Do.
3 [3]	7.8	6.26	3.01	1.5	Do.
4	9.1	21.36	25.29	3.6	Cotton (green manure).
5	7.0	27.77	24.63	2.7	Cotton (subsoiled).
6	9.0	20.89	27.83	4.0	Grass.
7	7.1	11.90	13.77	3.5	Cotton (green manure).
8	6.5	12.68	10.52	2.5	Cotton (subsoiled).
9	10.3	10.72	11.89	3.3	Cotton (green manure).
10	8.9	12.11	11.24	2.8	Cotton (subsoiled).
11 [4]	4.7	12.12	6.03	1.5	Cotton.
Average	8.2	15.52	15.43	2.9	

[1] Short plot.
[2] Long plot.
[3] Record for 5.55-inch rain of May 10 not included because tank overflowed.
[4] Desurfaced plot.

TABLE 8.—*Run-off and erosion data from the Hays, Kans., erosion station, 1930*

[Total rainfall, 22.78 inches; Colby silty clay loam; slope, 5 per cent]

Plot No.	Erosion ratio	Run-off	Erosion	Erosion per inch of run-off	Treatment
		Per cent	*Tons per acre*	*Tons per acre*	
1 [1]	19.6	12.68	1.99	0.69	Wheat.
2 [2]	15.7	12.49	3.22	1.1	Do.
3	17.9	12.72	2.13	.75	Do.
4	16.7	.69	.27	1.7	Grass (clipped).
5	16.8	12.56	3.37	1.2	Wheat.
6	17.5	15.96	6.95	1.9	Fallow.
7	16.7	19.01	3.05	.70	Kafir.
8	16.3	19.25	4.54	1.03	Do.
9	16.6	.06	.01	.70	Grass (not clipped).
10 [3]	24.1	12.17	2.62	.95	Wheat.
Average	17.8	11.76	2.82	1.07	

[1] Short plot. [2] Long plot. [3] Desurfaced plot.

TABLE 9.—*Erosion and run-off data from the Guthrie, Okla., erosion station, 1930*

[Total rainfall, 33.66 inches; Vernon fine sandy loam; slope, 7.7 per cent]

Plot No.	Erosion ratio	Run-off	Erosion	Erosion per inch of run-off	Treatment
		Per cent	*Tons per acre*	*Tons per acre*	
1 [1]	57.3	11.55	21.20	5.5	Cotton.
2 [2]	44.6	10.04	14.49	4.3	Do.
3	46.8	13.11	17.50	4.0	Do.
4	40.3	13.36	3.09	.69	Oats.
5	62.6	9.76	.51	.16	Sweetclover.
6	49.4	11.95	13.32	3.3	Cotton.
7	47.9	2.83	.064	.067	Grass.
8	45.4	22.95	18.09	2.3	Bare.
9 [3]	22.9	26.39	35.26	4.0	Cotton.
Average	46.4	13.55	13.73	2.7	

[1] Short plot. [2] Long plot. [3] Desurfaced plot.

TABLE 10.—*Erosion and run-off data from the Tyler, Tex., erosion station, October to December, 1930*

[Total rainfall, 11.57 inches; Kirvin fine sandy loam; slope, 8.75 per cent]

Plot No.	Erosion ratio	Run-off	Erosion	Erosion per inch of run-off	Treatment
		Per cent	*Tons per acre*	*Tons per acre*	
1 [1]	44.3	5.2	5.19	8.4	Cotton.
2 [2]	39.5	5.4	7.50	11.7	Do.
3	42.0	5.4	5.18	8.1	Do.
4	43.3	6.0	6.84	9.6	Do.
5	33.7	5.8	2.61	3.8	Do.
6	40.0	5.8	2.63	3.8	Corn.
7	35.9	5.6	2.40	3.6	Kobe Lespedeza.
8	28.6	9.3	.62	.56	Grass.
9	31.6	11.2	1.80	1.35	Bare.
10 [3]	8.6	.8	.06	.63	Cotton.
11 [3]	8.5	2.5	.03	.10	Do.
12 [3]	8.6	2.9	.25	.73	Do.
Average	30.4	5.5	2.93	4.4	

[1] Short plot. [2] Long plot. [3] Desurfaced plot.

It is not within the province of this bulletin to discuss the effect of the different crop treatments in the control of erosion. However, the correlation of the physical and chemical properties of the soil with its erosional characteristics is an important consideration. The dispersion ratio, the colloid-moisture equivalent ratio, and the erosion ratio are the only criteria that have been developed for estimating, in advance of actual measurement, the erosivity of a soil (*17*). These tests, of necessity, leave out of consideration differences in topography, climate, vegetation, and treatment, which are of primary importance in determining actual erosion except so far as these factors have previously influenced the character and properties of the soil itself. In consequence of these variables the degree of reliability of the erosional characteristics of the soils can not be estimated by com-

parison of the run-off and wash-off data of the different stations, but can only be arrived at by a study of the results obtained in successive years on plots under like treatment at a given station. However, some interesting relations may be brought out by the following discussion.

Houston black clay (Table 7), although it has the least slope and the lowest erosion ratio, shows the greatest average annual erosion and the highest percentage of run-off of the four soils for which data are available. It also has the greatest quantity of erosion per inch of run-off of the three soils for which data are available for the entire year.

The physical properties of this soil, such as the dispersion ratio, erosion ratio, and colloid-moisture equivalent ratio, would indicate that it is relatively nonerosive. The average dispersion ratio of the surface soil, 11.0, is within the tentative limit set by Middleton (*17*) for nonerosive soils, but the average of the colloid-moisture equivalent ratio, 1.29, is much below the lower limit of 1.5 which was established for this ratio. However, the average value of the erosion ratio of the surface soils, 8.5, is within the limit established for nonerosive soils. It is evident that some other property or combination of properties must operate in this particular soil to produce more erosion than would be expected from its physical properties. This soil is very stiff and plastic when wet and on drying shrinks and cracks into very hard lumps which adsorb water very slowly. Slow penetration of water, together with the high intensity of rainfall which occurs in this region, produces a large quantity of run-off. Under these conditions cultivation, such as is necessary in the growth of cotton, induces a large quantity of erosion because the loose surface soil is swept off by the run-off water. The low dispersion ratio is undoubtedly caused by the slow penetration of water into the aggregates of the soil and the high content of calcium which tends to hold them together so that under the conditions of this test only a small fraction of the material is dispersed. The dispersion and erosion ratios of the surface layer of the desurfaced plot (plot 11) are approximately half of the corresponding values of the normal surface soil, and the actual erosion is also approximately half as much. The colloid-moisture equivalent ratios are practically the same, so that in this case the dispersion ratios and consequently the erosion ratios indicate the relative degree of erosion.

The Houston soil is one of the most uniform soils that has been investigated in this work (Table 5); yet on two plots of this soil receiving identical treatment the erosion and run-off on one is nearly two and one-half times that on the other. (Plots 5 and 8.) The difference in the erosion ratios and in the other properties of these two plots (Table 4) give no indication of the cause of these differences. The erosion per inch of run-off is practically the same in each case, which is in accord with the physical and chemical data. The causes of these variations and discrepancies are not known at present. It is possible that they may disappear in later data; if so, they may be ascribable to local variations in treatment or in the establishment of the plots. The grass plot (No. 6) had the most erosion of any of the plots. However, this erosion all occurred in the first half of the year and no doubt was caused by difficulty in getting the grass estab-

lished. The effect of this is more or less counterbalanced in the average by plot 3, where the tank overflowed during the most destructive rain of the year.

Colby silty clay loam (Table 8) has the lowest annual rainfall, the lowest quantity of erosion, and the lowest erosion per inch of run-off of the four soils considered. The surface horizon of the plots, however, has a higher erosion ratio than that of the Houston soil and a much lower ratio than have the Vernon and Kirvin soils. The Houston and Colby are both calcareous soils, but the surface soil of the Colby is much lower in carbonates than the Houston surface soil. the variation noted may therefore undoubtedly be ascribed to the effect of the high carbonate content on the structure of the Houston soil. The erosion ratio for the desurfaced plot (No. 10) is not only higher than for the corresponding depth of the normal plots, but is also higher than for the surface layers of the same plots. Nevertheless, its actual loss by erosion is less than that of plot 5 and greater than that of plot 3, which have received identical cultural treatment. It may again be assumed that the exposure of the subsurface soil has resulted in structural alterations affecting its erosional behavior. It is to be noted that the upper layer of the desurfaced plot has an erosion ratio approximately threefold that of the material at approximately like depth in the profile sample (Table 4).

Vernon fine sandy loam (Table 9) has nearly the same percentage of run-off and total erosion as the Houston soil, with practically the same total quantity of rainfall. The Vernon soil is on a steeper slope, which produces more erosion per inch of run-off on the cotton plots than on the cotton plots of the Houston soil. The erosion ratio of the Vernon is more than double that of the Colby, and the average erosion is nearly five times as much. On plots receiving somewhat similar treatment, such as the oat and grass plots on the Vernon soil as compared to the wheat and grass plots on the Colby, the erosion is practically the same, with the Vernon showing less erosion per inch of run-off. However, the bare plot on the Vernon shows two and one-half times as much erosion as the fallow plot on the Colby. Taking the differences of slope, rainfall, crop conditions, and treatment into consideration, it is evident that the Vernon is a much more erosive soil than the Colby, as is indicated by their erosion ratios.

The desurfaced plot on the Vernon soil (plot 9) shows an unusual quantity of run-off and erosion, considering its erosion ratio and other physical properties. The erosion per inch of run-off is the same as for the normal plot 3. We are not able to offer a satisfactory explanation for this at present. It will be very interesting to see whether these differences continue to appear in successive years.

The data for Kirvin fine sandy loam (Table 10) cover only a part of a year, but they indicate that, considering the slope, the erosion ratio, and the high erosion per inch of run-off, this soil is highly erosive. The dispersion ratio, colloid-moisture equivalent ratio, and erosion ratio of the exposed horizon of the desurfaced plots are all within the limits tentatively established for nonerosive soils. The limited data show that these plots erode markedly less than any of the normal plots, regardless of treatment.

GENERAL REMARKS

The data presented in this bulletin concerning the chemical and physical properties of the soils on which erosion experiment stations have been established represent the beginning of an intensive laboratory study of the properties of soils which affect erosion and of the effect of erosion on soils. As the experiments proceed, these data will be used as the basis to which future analyses will be referred in order to determine the changes, if any, which are brought about in the soil by erosion. It is evident that when the chemical and physical properties are uniform throughout the soil profile, as in the Colby, Houston, Marshall, and Palouse soils, erosion will not extensively change the fundamental properties of these soils. The greatest change will be in the loss of organic matter from the surface soil, with consequent changes in water-holding capacity, plasticity, and structure. In the soils which are not uniform throughout their profiles, greater changes may be expected, particularly where the surface soil is of a sandy texture. It is to be expected that the removal of the surface soil will ultimately result in the present subsoil becoming the surface layer, except as the subsoil itself may be modified by erosion. This transformation will be gradual and will be greatly modified by cultural practices. With the present data and reserve material for future determinations, it will be possible to follow these progressive changes.

There will undoubtedly be great differences in the quantity of erosion which takes place on the different soils and on the same soils with different crop and fertilizer treatments. The field data at the time of writing this report are too meager to warrant the drawing of any definite conclusions. It is recognized, however, that any quantitative estimate of the validity of the laboratory data must be based on the field data when they shall have been obtained in adequate quantity. From the laboratory data at hand it is possible to predict with a high degree of certainty the type of erosion which will occur on a given soil type. It is also possible to predict which part of the profile will be most susceptible or most resistant to erosion. However, it is not possible to estimate the quantity of erosion, owing to differences in slope, quantity and character of rainfall, and type of agriculture. The whole investigation points to the urgent need for some method of ascertaining the relationship between structure and seasonal changes in structure and erosional behavior. It is probable that a complete picture should also include determinations of plasticity, percolation, and shrinking and swelling. It is highly probable that some determinations of this kind, together with the data reported herewith, may be correlated with the field data when available so that an adequate approximation of the field erosional behavior of soils may be made which will be extremely valuable in determining the need for, and methods of, erosion control in areas where for any reason the establishment of field stations is impossible.

SUMMARY

Mechanical analyses and gross chemical analyses have been made of representative profile samples of each of the soil types on which erosion experiment stations have been established.

Detailed chemical analyses of the colloids of each soil type have been made.

The physical characteristics affecting erosional behavior have been determined and a study made of their relation to each other, to the chemical composition of the colloid, and to field erosional behavior, so far as the latter is known at the present time.

The physical characteristics of composite samples from each tank plot at six of the stations have been determined.

An analytical basis has been established, to which may be referred the future field behavior of these soils when it has been determined, so that a quantitative expression of anticipated behavior may be developed.

The need for accurate quantitative expression of the effect of soil structure on erosional behavior has been pointed out.

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TECHNICAL BULLETIN No. 315 AUGUST, 1932

SOIL SURVEY (RECONNAISSANCE) OF ST. CROIX ISLAND VIRGIN ISLANDS

BY

JAMES THORP

Junior Soil Surveyor, Soil Investigations
Bureau of Chemistry and Soils

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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CONTENTS

	Page		Page
Area surveyed	1	Soils and crops—Continued.	
Climate	3	Soils of group 3	17
Agriculture	5	Soils of group 4	18
Soils and crops	8	Irrigation and alkali	19
Soils of group 1	11	Soils and their interpretation	20
Soils of group 2	13	Summary	27

AREA SURVEYED

St. Croix, the largest of the American Virgin Islands, lies in the Tropical Zone, between 64° 34′ and 64° 54′ west longitude, with a mean north latitude of 17° 44′. (Fig 1.) It is slightly more than 22 miles long in a nearly east-west direction and includes a land area of about 82 square miles. The western half of the island averages nearly 6 miles in width, but the eastern half tapers to a point. St. Thomas, the nearest large island, lies 40 statute miles to the north.

FIGURE 1.—Sketch map showing location of St. Croix Island, Virgin Islands

The island may be roughly divided into four principal physiographic divisions as follows:[1] (1) The northwestern mountainous area, (2) the southwestern and south-central coastal plain, (3) the north-central hilly area, and (4) the eastern mountainous area. These areas will not be further delineated as the reader may readily gain a full understanding of them by consulting the accompanying topographic and soils map.

The mountainous areas include some lands that have sufficiently gentle slopes to allow cultivation, and, in the northwestern mountainous section, they also include small alluvial valleys which abut

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on the sea or on the adjacent coastal plain. The coastal plain is prevailingly flat and has a gentle seaward slope. A few rounded limestone hills interrupt the smooth topography. The inner margin of the plain is covered by a series of broad alluvial fans extending out from the mountains. The north-central hilly area consists chiefly of rounded limestone hills and narrow flat valleys. Most of the small valleys and some of the hillsides are under cultivation, but much of this hillside land is too steep for the economic production of crops except forest trees and pasture grasses.

Natural drainage in the mountainous areas ranges from good to excessive, but in some places on the flat coastal plains drainage is rather poor. Where the soils are underlain by soft marly limestones local underdrainage is sufficient to take care of all normal precipitation. In scattered places along the seacoast are many areas of land, most of them bordering lagoons, which have very poor natural drainage and which, as a consequence, have accumulated harmful quantities of soluble salts.

The general level of the mountain tops of St. Croix is between 600 and 800 feet above sea level. Mount Eagle, the highest peak, extends to an altitude of 1,165 feet. The central hilly part of the island has a maximum elevation of nearly 600 feet. The coastal plain, where it abuts against the mountains, ranges in altitude from 100 to 200 feet and has a long flat seaward slope. In a few places on the seaward edge of the coastal plain are low sea-cut cliffs, few of which exceed 20 feet in height.

The natural vegetation of the island varies somewhat in different parts. The northwestern mountainous region supports a fairly dense tropical forest in the areas that have never been cleared. The individual trees are not large, but the undergrowth of thorny bushes and shrubs is so dense that penetration is extremely difficult. A large amount of the original timber has been cut and made into charcoal. Uncultivated parts of the coastal plain are either grown up to thorny brush or have been planted to pasture grasses. "Hurricane grass," which is considered of inferior feeding quality, has recently been spreading rapidly over the southwestern coastal plain and adjacent mountainous regions. Unless checked it bids fair to choke out other valuable grasses and perhaps may even replace some of the timber. In the eastern mountainous part of the island is a vast area of land that is so densely covered with thorny bushes and cacti that it can be penetrated only by goats. The brush has been cleared away in some places and the land planted to pasture grasses, but the brush retakes the land within a few years unless the owner wages a constant battle against the young bushes which rapidly shoot up. The chief vegetation in the central hilly part of the island consists of thorny brush with here and there groves of mahogany trees which were introduced into the island a long time ago.[2]

St. Croix Island was discovered by Christopher Columbus, who landed at the mouth of Salt River in 1493. It was subsequently owned by the Dutch, British, and Spanish. In 1651 it was taken by the French and presented in 1653 to the Knights of Malta. Denmark

[2] BRITTON, N. L., and WILSON, P. DESCRIPTIVE FLORA—SPERMATOPHYTA. *In* Scientific Survey of Porto Rico and the Virgin Islands. N. Y. Acad. Sci., v. 5, pt. 2, 1924; v. 6, pt. 1, 1925.

purchased it in 1737, and from that country it, with the other American Virgin Islands, was purchased by the United States in 1917. For a long time all the labor of the island was performed by negro slaves, but slavery was abolished in 1848 after a violent insurrection.[3] The natives were granted full citizenship in 1927.

According to the 1930 census report, 84 per cent of the inhabitants of St. Croix Island are negroes, 12.1 per cent are of mixed blood, and 3.6 per cent are white. In 1930, St. Croix Island had a total population of 11,413, a decrease of 3,488 since 1917. The decrease is chiefly owing to emigration to the United States. There are only two cities on the island, Christiansted (locally known as Bassin), with a population of 3,767, and Frederiksted (locally known as Westend), with a population of 2,698.

The Virgin Islands, from the time of their purchase until the spring of 1931, were governed by the United States Department of the Navy. Since that time the Department of the Interior has taken over the government, and a civilian governor has been appointed by the President. Laws for the municipality of St. Croix Island are made by the colonial council which consists of a majority of elected members and a minority of appointed members.

A very good system of public roads, most of which have been surfaced with gravel, spreads over the island. Most of the sugarcane is hauled from the fields in small carts drawn by oxen, mules, or donkeys, loaded on trucks and trailers, and hauled to the mill. Vegetables, fruits, and small articles of merchandise are hauled in small 2-wheeled carts drawn by donkeys or small mules. A bus line carries passengers between the two cities, and there are several privately owned motor cars. Most of the roads are in fairly good repair. One steamship a week brings passengers and mail from Puerto Rico and St. Thomas. Several ocean freighters and passenger vessels stop at irregular intervals at Frederiksted for passengers and freight. Many sloops and schooners ply between St. Croix and the neighboring islands, carrying mail, cattle, freight, and passengers.

There are no factories of great importance on St. Croix Island. At present (1931) one factory at La Grange is producing sugar, and a small factory at Orangegrove produces commercial alcohol from molasses. In the cities a few joiners make very beautiful furniture from mahogany and other tropical woods, but this industry is carried on in a very desultory fashion. Fishing for fish, sea crawfish, turtles, and other sea food is carried on, and this industry could well be extended. Many kinds of excellent fish abound, which should provide a larger proportion of the food of the people than at present.

CLIMATE

Climatic data have been collected intermittently over a long period of years, but there are so many gaps in the records that it is impossible to obtain an accurate idea of average figures for the different parts of the island. Table 1 gives the available climatic data for Christiansted, and Table 2 gives the mean precipitation for other stations on the island.

[3] Encyclopedia Britannica. Ed. 14, v. 19, p. 825; and v. 23, p. 190–191, illus.

TABLE 1.—*Normal monthly, seasonal, and annual temperature and precipitation at Christiansted, St. Croix Island*

[Elevation, 25 feet]

Month	Temperature, mean	Precipitation		
		Mean	Total amount for the driest year (1922)	Total amount for the wettest year (1927)
	°F.	*Inches*	*Inches*	*Inches*
December	77.5	2.44	3.57	1.32
January	73.4	2.28	1.69	2.43
February	73.0	1.54	2.55	1.59
Winter	74.6	6.26	7.81	5.34
March	74.5	1.62	1.95	2.40
April	76.8	1.58	.45	2.49
May	78.8	2.64	.49	5.85
Spring	76.7	5.84	2.89	10.74
June	80.4	2.06	3.00	1.59
July	81.6	3.14	1.44	5.40
August	82.8	4.69	2.21	2.01
Summer	81.6	9.89	6.65	9.00
September	81.6	6.75	4.83	10.74
October	81.0	5.04	3.91	8.88
November	78.4	4.93	.72	6.09
Fall	80.3	16.72	9.46	25.71
Year	78.3	38.71	26.81	50.79

TABLE 2.—*Mean monthly, seasonal, and annual precipitation at Annaly, Experiment Station, Frederiksted, Bonne Esperance, and King's Hill, St. Croix Island*

Month	Annaly	Experiment Station	Frederiksted	Bonne Esperance	King's Hill
	Inches	*Inches*	*Inches*	*Inches*	*Inches*
December	3.70	2.79	3.82	2.87	2.72
January	3.60	2.70	2.79	2.68	2.50
February	3.01	1.99	2.58	1.94	2.44
Winter	10.31	7.48	9.19	7.49	7.66
March	2.46	2.35	2.57	1.83	2.10
April	3.19	1.77	2.23	1.85	1.98
May	3.57	2.60	3.28	2.53	2.78
Spring	9.22	6.72	8.08	6.21	6.86
June	2.93	2.09	2.53	2.40	2.76
July	4.48	3.39	4.18	3.22	3.06
August	5.85	4.62	4.49	4.36	3.88
Summer	13.26	10.10	11.20	9.98	9.70
September	6.39	6.78	6.50	6.72	5.90
October	7.51	5.09	5.90	5.26	4.64
November	5.20	4.76	5.78	5.34	4.95
Fall	19.10	16.63	18.18	17.32	15.49
Year	51.89	40.93	46.65	41.30	39.71

The total amount of precipitation varies greatly from place to place and from year to year. The rainfall is fairly well distributed throughout the year, but the average for the fall is greater than for any other season. The precipitation is heavier in the western end of the island, especially in the mountainous country near Annaly, than it is in the central and eastern parts. The precipitation rapidly decreases toward the eastern point of land, and the vegetation in that part of the island is very similar to the bushy growths characteristic of the arid regions of the southwestern part of the United States. The prevailing winds are slightly north of east. This is indicated by the direction in which the bushes and trees on exposed slopes have been forced to grow on account of the nearly constant trade winds. The branches and tops of the majority of these trees and bushes point nearly due west.

AGRICULTURE

In the early days St. Croix Island was a very important center for the manufacture of sugar, molasses, and rum, and it was mainly to these products that she owed her wealth. Since the passing of the eighteenth amendment the commercial manufacture of rum has ceased. The curtailment of its production probably has little effect on the income of the islanders at present, as rum prices have been so low during the last few years that neighboring islands have been able to make little or no profit. During the World War good profits were made on sea-island cotton, but the pink bollworm and recent low cotton prices have driven the production of this commodity entirely from the island. At the present time (1931) agricultural production seems to have struck the lowest possible ebb other than the total abandonment of the island.

The descendants of the negro slaves furnish the labor necessary for the production of agricultural crops. The common wage ranges from 50 to 60 cents a day, but skilled laborers are paid somewhat higher prices. At present there is much unemployment on the island, owing to the fact that many of the estates are not in operation and to the decline of the sugar industry.

Of the total land area of the island 87.4 per cent is included in 193 farms. The average size of farms is 244.3 acres. In 1930, owners operated 47.2 per cent of the farms; tenants, 35.7 per cent; and managers, 17.1 per cent. The greatest number of farms (77) are in the group ranging in size from 3 to 9 acres. Only 11 holdings include 1,000 or more acres at the present time.

Many of the larger estates were established long ago. The owners built beautiful and substantial palatial homes of stone and surrounded them with well-built quarters for their slaves. On most estates, two or three large windmills were used for grinding sugarcane, and there was a building in which to boil the juice. Most of these old estates are now in ruins. All that remains of the old windmills are the massive stone towers, which so far have defied the elements. A few of the estates are kept in good repair by their resident owners, but it may safely be said that unless there is a revival of agriculture in the near future, most of the farm buildings and equipment will be beyond reclamation.

Among the agricultural products in 1929, sugarcane occupied the largest acreage. (Pl. 1, A.) Guinea grass is the principal grass grown. (Pl. 1, B.) In 1929, only 19 acres were devoted to corn, 14 to sweetpotatoes and yams, and 19 acres to onions. Other vegetables grown for sale include cabbage, eggplant, green beans, okra, peppers, squash, and tomatoes.

Much of the farming is done by hand labor, partly because of the prevalence of low-priced labor and partly because the operators of small farms are unable to buy machinery. Some modern machinery is being used in connection with the production of sugarcane. Draft animals include oxen, donkeys, mules, and a few horses.

The island is well supplied with churches and schools. Native teachers are employed chiefly.

The principal agricultural industry of the island is the raising of cattle. The animals are chiefly of the breed introduced by the Spaniards into Puerto Rico and other West Indian Islands. These animals are used for work animals and to a certain extent for dairy purposes. On many estates they are being crossed with Brahman cattle which are immune to tick fever. The bullocks are used for work animals on the island, and some are shipped to Puerto Rico for the same purpose. Many cattle are sold to Puerto Rico dealers to be used for beef. Extensive areas of hill land in the eastern part of the island have been cleared and planted to pasture to support the cattle industry, and there are also large areas of good pasture land in the southern and southwestern parts of the coastal plain and in the hills near Two Williams. The cattle industry could be greatly extended without greatly disturbing the arable lands by clearing off brushy areas in the eastern and other hilly parts of the island. At present, the dairy industry is unimportant, but it probably could be profitably extended.

A few horses for riding and mules for working are bred, but this industry is not important. There are a great many donkeys on the island. They are used for pulling small carts, for packing, and for riding to a limited extent. Most farmers have a few chickens and hogs, which are raised mainly for home consumption. One fair-sized herd of sheep was observed. These animals are raised for food and produce a good quality of mutton. There are many goats in the eastern part of St. Croix Island and on Buck Island.

If all parts of the sugarcane plant except the commercial product, sugar, could be returned to the soil, there would be very little need for the use of fertilizers on most sugarcane soils, as sugar itself removes very little from the soil, being composed only of carbon, hydrogen, and oxygen, none of which comes from the soil.[4] However, molasses, which is sold, bagasse which is burned, tops which are fed or burned, and leaves, which in St. Croix are generally burned, all contain plant-food elements removed from the soil. Thus, it is apparent, constant depletion of the soil of the island is in progress.

In past years it has been the practice to apply from 20 to 30 tons of farmyard manure an acre each time a new crop of sugarcane is planted. The manure included cane trash or leaves, weeds, the re-

[4] Information on fertilization and preparation of the land on St. Croix Island is furnished by M. S. Baker, former agronomist at the Virgin Islands Agricultural Experiment Station, St. Croix.

mains of grass, and cane tops hauled to the pens for feed, in addition to the excreta of the animals. Farmyard manure applied at this rate will supply adequate plant food, but, with the advent of tractors and modern farm machinery, there is not sufficient manure to meet the demand. It has been suggested that the cane growers buy manure from the cattlemen, but the cattlemen do not pen their livestock but allow them the run of the pastures which need the manure thus supplied. The planter should use all the available manure because it contains the essential plant foods, acts as an indirect fertilizer in liberating plant food already in the soil, and adds humus to the soil, thereby improving the physical condition and increasing the water-holding capacity, a factor of much importance in the Virgin Islands.

Naturally when the supply of farmyard manure is not available in sufficient quantities, the question of substitutes arises. The only substitute for farmyard manure is a green-manure crop, preferably a leguminous crop, to be plowed under. However, the practice of growing such crops is not followed by St. Croix planters, largely because of weather conditions, which have not been considered suitable for the planting of such crops before cane-planting time. Depending on rainfall, there are from three to five months during which green-manure crops could be planted. Probably the sugarcane planter would eventually be much better off if he rotated his cane with such crops, even though he were to lose the use of a small part of his acreage during one planting season.

Crotalaria juncea, cowpeas, velvetbeans, jack beans, and pigeon peas, named in the order of their importance, are all good green-manure crops that could and should be grown. *C. juncea* is ready for turning under 60 days after planting, with 8½ tons of green matter an acre; cowpeas and velvetbeans in 75 days, with 10 to 14 tons an acre; and jack beans in 90 days, with 7½ tons. Several native leguminuous plants, that promise to be of value, are under observation.

Experiments with fertilizers carried on at the experiment station several years ago indicated that the use of commercial fertilizer was not profitable, owing to the prevailingly dry weather, and at present commercial fertilizers are not used by St. Croix sugar planters. If irrigation were practiced, commercial fertilizers would undoubtedly prove profitable. Near-by cane-growing areas are benefiting from applications of commercial fertilizers.

When the final crop of cane has been removed from the land, preparation begins for the next planting which is to remain on the land for at least 32 months. All trash left on the land, together with what little vegetable matter there may be, is generally burned. This is bad practice, because it destroys plant food and humus. After the trash has been burned, the land is turned to a depth of 8 or 10 inches. A large part of this work is still done with oxen, usually 8 oxen drawing an ordinary moldboard plow. Two teams a day, morning and afternoon, are required, making 16 oxen and three men a day for each plow used. This outfit will turn from one-half to three-fourths acre a day. On the holdings of the West Indian Sugar Co., tractors, as well as oxen, are used for this work, but the equipment of these farms does not allow all the land to be broken with tractors. Renters of small plots turn and prepare their land by hand, using spading forks.

After breaking, the land is harrowed and then either thrown into a series of high ridges, called banks, or marked off with shallow furrows. The last method, which is the most desirable, is becoming more and more popular. The rows are spaced 4½ or 5 feet apart and the cane cuttings planted 2½ or 3 feet apart in the bottom of the furrows in single rows.

Most of the cane is planted between September and December, but it may be profitably planted until the middle of January. During the normal planting season, September to December, practically the whole cane is used for planting. Each stick or cane is cut into pieces having from two to four eyes. If cane is planted during the dry season so-called "tops" are preferred. These consist of the upper four or five joints of the cane stick from which the growing point has been cut away. From 3,600 to 5,000 of these cuttings are planted to the acre. The "plant tops," as these pieces of cane are called, are planted by hand, the workman using either a pickax or a crowbar with which to open a hole in the bottom of the furrow. Into these holes he slips the plant tops. One man will plant about 3,000 tops a day.

SOILS AND CROPS

Since the first settlement by white men, St. Croix has been almost entirely an agricultural island. For a long time sugarcane was the only commercial crop of importance. It was used for the manufacture of sugar and rum. The cane juices were extracted by mills operated by wind power, and the raw sugar was extracted from these juices in old-fashioned open pans. Later, more efficient machines were introduced, but even these are now out of date, according to present standards of efficiency. Although the soils are admirably adapted to sugarcane, the comparatively dry climate and persistent droughty weather over a period of years has greatly reduced the yields, and recent low sugar prices have prevented capitalists from investing their money in new machinery or in the production of cane on a large scale. In consequence, the cane-growing industry is rapidly diminishing in volume. The soils of the island are well suited to sea-island cotton, and good yields can be produced with much less water than can sugarcane, but the appearance of the pink bollworm, together with reduced prices for the staple, have forced the planters to abandon this crop temporarily. Very recent investigations by entomologists have shown the bollworm to have been so nearly exterminated by closed seasons on cotton growing that an attempt is to be made by the Federal experiment station, cooperating with the planters, to produce a crop of cotton on a small acreage in the near future.

Many different vegetables and tropical fruits have been successfully grown and could be produced in large quantities if a profitable market could be found. Tomatoes, beans, peppers, bananas, sapodillas, avocados, pineapples, and citrus fruits do well in certain parts of the island. A number of thrifty-looking date trees were observed in various parts of the island. These trees are said to produce a fair quality of fruit, and it would seem advisable to experiment with different proved varieties with a view to growing dates on a larger scale. Dates thrive in moist soil and are resistant to moderate con-

A, Young sugarcane growing on Fredensborg clay. Slob estate headquarters at the left. Mount Eagle and Blue Mountain in the background; B, Guinea grass pasture on Descalabrado clay and its steep phase near Lowry Hill, St. Croix Island. Note the dense growth of thorny brush on the mountain in the background

centrations of salts. They would probably flourish in some of the poorly drained areas of the coastal plain where the salt accumulations are not too strongly concentrated. Alfalfa would probably thrive in many parts of the island where there are no salt accumulations and might prove to be a valuable addition to the forage supply for cattle and horses.

At the present time there is no way to ship perishable crops to the markets of the United States or Europe, but it is reasonable to suppose that steamers with refrigerator compartments would operate if a steady business were in prospect. Of the perishable crops, tomatoes, peppers, and green Lima beans seem to be the most promising. The production of pineapples, as will be shown, will of necessity be very limited. The chief limits to the quantities of other crops which can be grown will be set by the amount of rainfall available in a given year and by the local or export demand, together with the degree of aggressiveness of the people who produce the crops.

Many parts of the island are so hilly or so stony that they are suited only for forestry or pasture. A fairly large cattle-raising industry is thriving on such lands.

In view of the prevailing low sugar prices, poor facilities for sugar production, and the comparatively dry climate of St. Croix Island, it seems likely that the cane industry is doomed to ultimate extinction unless sufficient water be found for irrigation. If the sugar industry becomes extinct it will be necessary to adopt new crops and produce new products to take its place.

Nearly all the arable soils of the island will produce good crops of vegetables and fair crops of corn, and many soils are well adapted to a large variety of fruits. The untillable hilly lands will produce excellent pasturage which is sufficient for enough animals to provide milk and meat for the populace and for a good export trade as well. It is easily possible, therefore, for the island to produce nearly everything the people need to eat and have a comfortable surplus of many of the food crops. The mountainous and rocky land will produce excellent mahogany and other tropical woods on the slopes that are sheltered from the trade winds and, with proper forestry methods, after a period of years would furnish a steady cash crop. For more immediate returns it would seem that the production of dry beans for the Porto Rico market should prove highly profitable. There are tremendous areas of soils suited to this crop. If the pink bollworm and other pests can be kept under control the production of sea-island cotton should provide a substantial export item. Pineapples and citrus fruits have been suggested as possible export crops, but it is not likely that either crop can be grown in greater quantities than are sufficient for local demands. Especially is this true of pineapples. This crop prefers distinctly acid soils, and no soils were observed in St. Croix that were more than slightly acid. The citrus-fruit outlook is brighter, but the fruit would have to come into competition with that from Puerto Rico and Florida. Fresh vegetables for the winter markets of New York might prove profitable provided transportation could be obtained. A few cacao trees are scattered over the island, and they seem to thrive in the northwestern mountains and valleys. It would probably be well to experiment with the production of cacao in this region with a

view to possible expansion. With the increased consumption of cashew nuts in the United States, there is increased possibility of commercial production of this crop in the American Tropics.

The possibility of growing certain important insecticidal plants on the island is also under consideration by scientists of the Bureau of Chemistry and Soils.

In the past, the soils of the island have been classified loosely from a geological point of view. Two chief geological formations have been recognized. The first is known as the "older series," or "blue beach" in more common language, and the second is known as the "younger series," or "marl" formation. The blue beach consists of a great series of highly stratified extrusive volcanic tuffs and shales, with many dikes and sills of intrusive hard igneous rocks. These are interstratified here and there with hard limestones and limy shales, which also include some volcanic materials. Soils from materials that have been washed out from the blue beach have been classified with this series. Marl soils are those which have been derived from any of the harder or softer layers of the younger series of marls and limestones.

TABLE 3.—*Acreage and proportionate extent of the soils mapped on St. Croix Island, Virgin Islands*

Type of soil	Acres	Per cent	Type of soil	Acres	Per cent
Fredensborg clay	1,984	3.8	Barrancas clay	64	0.1
Diamond clay	512	1.0	Cornhill clay loam	2,368	4.5
Diamond clay, deep phase	832	1.6	Lavallee clay loam	576	1.1
Sion clay	960	1.8	Orangegrove loam	128	.2
Sion silty clay	512	1.0	San Anton loam	3,136	6.0
Coakley clay loam	2,688	5.1	Descalabrado clay	5,888	11.2
Aguilita clay	4,096	7.8	Descalabrado clay, steep phase	14,720	28.0
Aguilita clay, shallow phase	512	1.0	Descalabrado clay, shallow phase	2,176	4.1
Aguilita clay, steep phase	1,600	3.1	Parasol clay loam	448	.9
Hesselberg clay	1,856	3.5	Serrano clay loam	768	1.5
Hope clay	2,368	4.5	Jaucas sand	896	1.7
Santa Isabel clay	1,792	3.4			
Granard clay	512	1.0	Total	52,480	
Glynn clay loam	1,088	2.1			

Following a reconnaissance soil survey, the soils of the island were classified according to the following characteristics: (1) Color; (2) structure, or character of soil aggregates; (3) consistence, or degree of plasticity, friability, and other characteristics; (4) presence or absence of lime ($CaCO_3$); (5) presence or absence of harmful quantities of soluble salts; and (6) character of parent materials. Careful separations on the basis of texture were not recorded because the textures of the soils of the island are almost uniformly very heavy. This characteristic was, however, taken into consideration in a general way. The soils were examined to sufficient depth, wherever possible, to determine the characteristics of all horizons from the surface soil to the parent material. On the basis of these observations the soils are classified in soil series, types, and phases. Each type and phase is indicated on the map by an appropriate symbol. Nineteen soil series comprising 20 soil types and 5 phases are mapped. For convenience in discussion and in making practical use of this survey, these soils may be placed in four groups, as

follows: Group 1, soils underlain by limestone or marl, generally shallow, but fertile; group 2, soils underlain by alluvial deposits, generally deeper than those of group 1; group 3, soils derived from old volcanic rock material, mostly shallow and on rough topography; and group 4, miscellaneous recent deposits.

In subsequent pages of this report, the soils of St. Croix Island, Virgin Islands, are described in groups and in detail. The accompanying soil map shows their distribution over the island, and Table 3 gives the acreage and proportionate extent of each soil mapped.

SOILS OF GROUP 1

The soils of group 1 are all locally called marl soils, and they are the most important agricultural lands of the island from the point of view of the area involved, but there are other soils which are potentially more productive though less extensive. In this group of soils are placed seven soil types and three phases which are described in the order of their importance.

SUBGROUP A

Five of these soil types and one phase belong to a subgroup in which the soils have several characteristics in common. To a depth of 9 or more inches they have dark surface soils of granular structure and good tilth. Beneath the surface soil is a thin transitional zone of mixed organic soil and marl underlain by marl or soft limestone at a comparatively slight depth. In a few places are "slick spots," where a slight accumulation of sodium carbonate or other salts has rendered the soil unproductive. One of these is near the new well at Anna's Hope. The surface soils have good moisture-holding capacity, but the substratum is so porous that the subsoils do not hold moisture during very long dry periods. These soils are capable of producing excellent crops when moisture conditions are at all favorable. Many of the formerly prosperous sugar estates are located on these soils, and in favorable years good crops of cane may still be produced. (Pl. 1, A.) Many varieties of vegetables will grow and produce excellent yields. The soils are well adapted to the growing of dry beans of various sorts, and it seems likely that the bean crop would be one to be emphasized in a program of agricultural readjustment. Puerto Rico, which is within easy reach by sloop or steamship, offers a market for dry beans. Tomatoes, peppers, Lima beans, sweetpotatoes, corn, cotton, and many other crops are adapted to these soils.

The following brief descriptions indicate the differences between the different types of this subgroup of soils:

FREDENSBORG CLAY

The surface soil of Fredensborg clay is very dark gray granular clay which is plastic when wet. This layer, which ranges from 10 to 15 inches in depth, lies on a thin transitional zone of gray, mottled with yellow and white, clay which is, in turn, underlain by a very porous loose somewhat yellow marl or soft limestone. The soil throughout the entire profile is rich in lime carbonate. The granular structure of the surface material causes the soil to have excellent

tilth except immediately following heavy rains. A phase of Fredensborg clay, having a distinctly black surface soil, was recognized but not separately mapped because of its small total area. The occurrence of such an area was noted at Bethlehem, about midway between Christiansted and Frederiksted.

DIAMOND CLAY

Diamond clay is brown and granular but less plastic than Fredensborg clay. Marl occurs at a depth of about 1 foot. This soil is well adapted to vegetables and cane and would doubtless produce excellent yields of cotton. On the whole it is probably somewhat less productive than Fredensborg clay. Some salty spots occur near the seacoast.

DIAMOND CLAY, DEEP PHASE

The deep phase of Diamond clay is like the typical soil except that the brown surface layer in the phase extends to a depth of 2 feet. It is somewhat more productive than the typical soil because of the deep topsoil and the consequent greater moisture-holding capacity.

SION CLAY

Sion clay consists of medium-gray or dark brownish-gray granular friable clay to a depth of about 9 or 10 inches. It has the usual 3 or 4 inch transitional zone, and white or yellow marly lime occurs at a depth ranging from 12 to 15 inches. This soil is naturally very fertile, but it is more subject to droughty conditions than the more plastic Fredensborg and Diamond clays. There are some local "slick spots." The same crops as are grown on Fredensborg clay and Diamond clay do well on this land.

SION SILTY CLAY

Sion silty clay is similar to Sion clay but differs from that soil in that it contains a larger proportion of silt materials, and in many places many fragments of soft limestone occur. This is the most extensive soil on the flat areas of the Federal experiment station. It is probably somewhat less productive than Sion clay because its water-holding capacity is less and because it contains less organic matter.

COAKLEY CLAY LOAM

The surface soil of Coakley clay loam is granular friable dark brownish-gray or gray material which contains many soft limestone fragments. At an average depth of about 10 inches it is underlain by white semi-indurated chalky limestone. Cane crops on this soil show much chlorosis and are seriously stunted by droughty weather. However, many species of trees and several kinds of pasture grasses do very well. Guinea grass is especially fine. During moist seasons this soil is productive of many kinds of vegetables.

SUBGROUP B

Subgroup B of group 1 includes two soil types and two phases. The Aguilita soils are usually dark, rather thin, and lie at widely different depths on moderately hard or soft Tertiary limestones.

They are adapted to a mixed agriculture. The smoother areas, in which the soils are deeper, are suited to vegetables, dry beans, corn, cane, cotton, and pasture grasses, and the rougher and more stony areas are suited to pasture or forestry. Mahogany trees do very well on the hillsides occupied by these soils. Guinea grass is one of the best crops for pasturage. Hesselberg clay is alkaline in reaction, as are the Aguilita soils, but it differs in color. It is very stony in most places, which makes it difficult to cultivate. Nevertheless it produces good crops of vegetables and cotton. It also affords excellent pasture after the bushes are cleared off and the land planted to guinea or other pasture grasses.

AGUILITA CLAY

The surface soil of Aguilita clay is more or less friable dark brownish-gray clay loam or clay, which ranges from 5 to 20 inches in thickness. It is very limy. The lighter-colored friable limy subsoil is only a few inches thick and directly overlies moderately hard Tertiary limestone which has many cracks and fissures, so that it can be permeated by roots to great depths.

AGUILITA CLAY, SHALLOW PHASE

Aguilita clay, shallow phase, comprises areas of bare or nearly bare Tertiary limestone. In many places a thin surface coating of soil similar to the typical soil occurs. The land supports a natural growth of thorny bush, and where this is cleared off, scanty pasture for livestock is available. The agricultural value of this shallow soil will never be high.

AGUILITA CLAY, STEEP PHASE

The steep phase of Aguilita clay comprises areas of limestone hills most of which are too steep or too stony for cultivation. These areas furnish good pasturage when cleared or planted to grass. Mahogany trees flourish on this steep land.

HESSELBERG CLAY

Hesselberg clay occurs in the southern and southwestern parts of the so-called "marl belt." To a depth of about 1 foot it consists of reddish-brown or brownish-red calcareous granular somewhat stiff clay which has very good tilth. It overlies rather hard fragmental limestone having red clay in the interstices. Solid rock occurs at a depth ranging from 15 to 24 inches. The soil has good moisture-holding capacity and is a good crop producer. Its stony character makes cultivation difficult. Before the advent of the pink bollworm this soil was extensively used for growing cotton. Very little cane was seen growing on this soil.

SOILS OF GROUP 2

The soils of group 2 occur on the flat coastal plains, alluvial fans, and terraces. The soil materials are almost entirely of fluvial origin, but weathering has produced different profile characteristics, largely according to the length of time the materials have been exposed to its influence. The composition of the materials from which these fluvial

deposits have been washed also influences the characteristics of the soils. Nine soil types were recognized and mapped and included with this group. They have been placed in three subgroups.

SUBGROUP A

Soils of subgroup A have heavy dark-colored somewhat granular surface soils, heavy very stiff and hard clay upper subsoil layers, friable or plastic limy lower subsoil layers, and, with one exception, more or less gravelly parent materials. In many places, which are indicated on the map with stone and gravel symbols, the surface soils contain enough loose stone or gravel to interfere more or less with cultivation. The heavy stiff character of these soils makes them difficult to handle and impairs their productivity. In the past these soils have been devoted mainly to cane and pasture. Probably they would produce good yields of cotton if it proves practical to grow cotton on St. Croix Island. In many places these soils show evidence of slight or moderate accumulations of soluble salts and black alkali, which, if they become more concentrated, will seriously interfere with crop production. Concentration of alkali is not very likely to take place unless the land is irrigated, and then it will be necessary to provide subdrainage.

HOPE CLAY

Hope clay is the most extensive soil of this subgroup. It occupies an almost continuous strip of territory from Whim and Hope to Bethlehem and Fredensfeld. The surface soil consists of a layer of dark gray-brown granular or finely cloddy very stiff clay about 6 inches thick, which in many places contains gravel. The surface soil in most areas is slightly calcareous. Underlying this layer is a 1-foot layer of heavy dark gray-brown or black exceedingly stiff granular or cloddy clay which grades into a 12-inch layer of heavy cloddy olive-drab calcareous clay. The deeper part of the subsoil consists of mixed gravels, clays, and sands, with a heavy accumulation of lime, some of which is concretionary. When at the proper moisture content this soil breaks up fairly well under the plow, but otherwise tillage is difficult. Most of this land shows evidence of slight or moderate accumulations of alkali, especially in the subsoil. The alkali spots are especially abundant where there is a sudden change in slope.

SANTA ISABEL CLAY

Santa Isabel clay resembles Hope clay in several respects but has many points of difference. It is lighter colored than that soil; plastic, instead of stiff and cloddy; has good tilth; and the heavy layer of the subsoil is not so intractable. This soil is more calcareous and is as subject to alkali accumulation as Hope clay, but it averages much higher in productivity. In places near the seacoast enough salts have accumulated in the surface soil to interfere with the maintenance of good tilth. These places are indicated on the soil map by appropriate symbols. Santa Isabel clay should prove to be superior to Hope clay as a crop producer.

GRANARD CLAY

Granard clay is derived largely from the more or less gravelly marl which lies at the base of the Tertiary deposits. Few crops other than pasture grasses were observed on it. The differences between this soil and Santa Isabel clay are largely of a technical rather than a practical character and hence will not be discussed in this part of the report. Probably this soil will prove to be of about the same productivity as Santa Isabel clay.

GLYNN CLAY LOAM

Glynn clay loam occurs in a strip parallel to the areas of Hope clay, between areas of that soil and the mountains. It has a 10-inch granular dark gray-brown clay loam surface soil of good tilth, a 12-inch brownish-yellow moderately stiff clay loam upper subsoil layer, a brownish-yellow limy clay loam lower subsoil layer extending to a depth of 3 feet, and a gravelly and sandy substratum. This is an excellent soil in most respects, but it does not contain so much organic matter as do the soils of group 1. It is well adapted to nearly every kind of crop grown in the island and especially to vegetables, fruits, and cotton. Citrus fruits would undoubtedly do very well on this land if irrigation could be provided. Pineapples of good eating quality were observed on these soils, although the soil is not particularly well adapted to the present commercial varieties of pineapples.

BARRANCAS CLAY

Barrancas clay occurs in a few places on the coastal plain. It occupies low imperfectly drained areas between the alluvial-fan deposits and the soils of the marl group. It has a heavy nearly black waxy surface soil and a mottled rust-brown and gray plastic subsoil. This soil is calcareous, has fair tilth, and produces fair crops of cane, but its position makes it susceptible to accumulation of salts or alkali. The largest area lies just north of Fredensborg, and an area occurs just south of Lower Love. The agricultural value of this land is limited by poor natural drainage.

SUBGROUP B

Subgroup B includes three soil types derived from terrace or alluvial-fan materials, which have been washed from the volcanic or "blue beach "rocks. They have brown surface soils, more or less well-developed heavy upper subsoil layers, and gravelly substrata. Two of the soils of this subgroup have definite accumulations of lime in the subsoil.

CORNHILL CLAY LOAM

To a depth of about 4 inches the surface soil of Cornhill clay loam is dark gray-brown fine-granular friable loam or clay loam. It is underlain by a 6-inch layer of nearly black stiff and cloddy gravelly clay which tends to run together when wet. The subsoil is light yellowish-brown plastic clay and contains a large quantity of accumulated lime. The substratum material is a mixture of alluvial gravel, sands, and clays. Some variation in this soil occurs from place to place. Large areas of stony or gravelly soil are indicated

on the map by gravel and stone symbols. In several places, particularly near Great Pond and Southgate, enough sodium carbonate is present to affect crops adversely.

In the past this soil has produced excellent yields of cotton, but the climate in that part of the island where it occurs is so dry that cane has never been an important crop. At the present time the land is being devoted to pasture or has been allowed to revert to primitive conditions. It is very likely that good crops of dry beans could be produced on those areas of Cornhill clay loam which are not too badly affected by accumulations of alkali.

LAVALLEE CLAY LOAM

Lavallee clay loam occurs on alluvial fans on the north coast of the island, from Sugar Bay to Ham Bay, and on the south coast, from Rod Bay to East Point. As mapped the soil is somewhat variable and might be subdivided if a detailed survey were made. The surface soil consists of granular light-brown gravelly clay loam, and the upper subsoil layer is reddish brown, heavy, and sticky. There is an accumulation of lime in the lower part of the subsoil, and the substratum materials are stratified sands, gravel, and clays. Stony areas are indicated on the map by stone symbols. The area of Lavallee clay loam mapped near Ham Bay is very stony and does not show well-marked layers in the subsoil. Some of the areas near the east end of the island also differ somewhat from the typical soil. It was impossible to examine these soils in great detail in the time available. Near Lavallee this soil produces fair crops of beans and vegetables. An old planting of citrus trees has survived but, owing to lack of care, has not thrived. Areas of this soil include small strips of San Anton loam which is a very productive soil where not too gravelly.

ORANGEGROVE LOAM

Orangegrove loam occurs on high stream terraces near Annaly and Orangegrove. It is characterized by a deep brown surface soil underlain by a reddish-brown somewhat heavy subsoil, beneath which is the stratified gravel and sand substratum. As the soil is deep in most places, it should be very productive. The reaction of the surface soil is neutral or very slightly acid, and for that reason this soil might prove to be a fair soil for pineapples. Cane and vegetables grow well, and the rainfall is usually sufficient for the maturing of crops. As mapped, this soil includes areas of stream-bottom land and small areas of Descalabrado clay. This is one of the most promising soils for the production of citrus fruits. Along the adjacent stream bottoms good crops of bananas and plantains are being grown, and the acreage in these crops could well be extended.

SUBGROUP C

Subgroup C of group 2 includes only one soil type, San Anton loam.

SAN ANTON LOAM

This soil occurs along stream bottoms and on alluvial fans, in and adjacent to the volcanic oldlands of the island. In very gravelly areas, which are indicated on the map by gravel symbols, the soil is

likely to dry out quickly after rains. Otherwise, this is an ideal soil. It is somewhat deficient in nitrogen but is rich in other necessary plant foods. One small area, lying about three-fourths mile west of Krause Lagoon, is so very sandy and gravelly that it is of no value except for pasture.

This soil has a brown or gray-brown friable surface soil and a somewhat lighter-colored subsoil. In typical areas the subsoil is not heavy but consists of recently deposited alluvial silts, sands, and gravel. In most places the profile is slightly calcareous throughout. In the reconnaissance survey it is not practical to separate all areas of this soil from the Cornhill and other soils with which it is associated. Therefore some areas shown as this soil on the map doubtless include a large total area of other soils. Where rainfall is sufficient, this soil is well adapted to any of the crops common to this region. It would make excellent citrus-fruit land provided enough moisture were available. Most of the soil is probably too high in lime for successful pineapple culture. Beans should do very well.

SOILS OF GROUP 3

The soils of group 3 comprise more than half the total area of the island, but much of the land involved is so steep or stony that it is of little agricultural importance. The smoother areas of these soils are very productive, however. The surface soils are almost universally dark colored and fairly high in organic matter. The subsoils are lighter colored and in many places have accumulated more or less lime. In a few places, which are not shown on the map, both surface soils and subsoils have a decided tinge of red. These areas are of little interest to the farmer, however, because most of them occur in places too steep or too stony for cultivation.

DESCALABRADO CLAY

The surface soil of Descalabrado clay is coarsely granular rather stiff brown or dark gray-brown clay about 1 foot thick. It is underlain by yellowish-brown slightly heavier clay which contains many rotten tuff fragments. At a depth ranging from 15 to 30 or more inches is rotten volcanic rock, most of which is tufaceous or shaly in character. Seams of accumulated lime occur in many places in the upper part of the parent material. Rock outcrops are shown on the map by rock-outcrop symbols.

This soil is widespread in the mountainous regions. In the western half of the island the land is extensively used for the production of cane, vegetables, and fruits, and in the drier eastern part it is either devoted to pasture grasses or has retained its heavy cover of bush and cacti. The comparatively prosperous farming district near Annaly owes much of its prosperity to this soil. Selected areas of the deeper soils of this type, in the western half of the island, should prove to be excellent citrus-fruit land. Pineapples grow better on this than on any other soil observed on the island, but, judging from observations on the reaction of soils producing pineapples elsewhere, the indications are that this soil is too nearly neutral or too alkaline to offer much hope for the extensive cultivation of this fruit. Pineapples evidently prefer highly leached medium acid or strongly acid soils.

DESCALABRADO CLAY, STEEP PHASE

The steep phase of Descalabrado clay resembles the typical soil in every respect except that it lies on slopes too steep for convenient cultivation. As mapped it includes very large areas of very shallow soils and large areas of very stony land. The rock outcrops observed are roughly indicated on the map by appropriate symbols. Doubtless there are other stony areas, not observed or shown on the map. This steep soil occurs in close association with the typical soil. In the western part of the mountainous region large areas of the steep phase are under cultivation and are giving satisfactory yields. Some of this steep land in the eastern part of the island is used for pasture.

DESCALABRADO CLAY, SHALLOW PHASE

This shallow soil consists of dark-brown granular loam or clay loam about 12 inches thick, which lies directly on rotten tufaceous shales. It is used mainly for growing guinea grass for pasture and produces good yields of this crop. It is too droughty for most cultivated crops. Steep areas of this soil were included on the map with Descalabrado clay, steep phase.

PARASOL CLAY LOAM

Parasol clay loam occurs only in one large area in the vicinity of River and Fountain. The surface soil is very dark colored and deep, and the subsoil is yellowish brown and overlies rotten volcanic rocks. In places there is an accumulation of lime in the subsoil. Toward the valley bottom colluvial wash makes the soil thicker than it is near the hills. The soil has good granulation and works up well under the plow. Its heavy texture and large organic-matter content should give it a high moisture-holding capacity. At present most of the land is devoted to cane but it should produce very good yields of corn, vegetables, dry beans, and fruits. It is regarded as naturally one of the richest soils on St. Croix Island.

SOILS OF GROUP 4

The soils of Group 4 include soils typical of the environs of the seacoast.

SERRANO CLAY LOAM

Serrano clay loam consists of a lagoon deposit of clays, sands, and loams which are gray, wet, and poorly drained. Most of the areas are more or less salty, and all of them are too near sea level for drainage without pumping. They have no agricultural value at present.

JAUCAS SAND

Jaucas sand is a pale-yellow sand made up almost entirely of coral fragments. It occurs in intermittent strips along the seacoast. In some places it is barren of vegetation, and in others it supports a growth of brush. It contains a moderate amount of organic matter. Some of the soil near Westend Saltpond has hardened into limestone.

Several small coconut groves are scattered over the Jaucas sand areas, and the trees seem to thrive. It would probably be well to extend such plantings.

IRRIGATION AND ALKALI

With the rather low precipitation over most of the island it would be very advantageous if a supply of water sufficient for irrigation could be obtained. Irrigation would be especially desirable in the so-called "marl belt" and on the alluvial fans of the eastern half of the island. There seems to be no hope of getting water for this section of the island, but some scientists believe that water might be obtained from certain parts of the lower Tertiary beds. Up to the present time no wells have tapped this horizon. Shallow wells have struck sufficient water for cattle but no supply large enough for irrigation purposes has been discovered. There are no reservoir sites that would furnish very large storage space and at the same time drain sufficient territory to assure a good volume of flood waters. The only hope for irrigation, therefore, and a slender one at that, is to tap the lower Tertiary beds in the hope of striking a good flow of water.

In case a water supply of considerable volume is found, it will be necessary to take precautions to use the water carefully and to dispose of the waste water in such a manner as to prevent the excessive accumulation of alkali and soluble salts. Alkali salts in small quantities were noticed in many places. Most of these areas, except those close to the sea or to lagoons, contain only enough alkali at present to slightly affect the soil. Irrigation would tend to concentrate the salts in low places where subdrainage is poor and along areas where there is a change in slope from comparatively steep to more gentle.

The accompanying soil map shows in a general way the location of the areas of soil that are affected by salts of various kinds. Sodium carbonate, commonly referred to as black alkali, was found affecting a few fairly large areas near Great Pond, the leper asylum, Southgate, Bethlehem, Castle Burke, and Jerusalem. It does not occur uniformly over the areas but in spots and streaks, especially in those places where sodium chloride has come in contact with limy soil or with the zone of lime accumulation in the soils that are noncalcareous in their surface horizons. It is especially common along the courses of intermittent streams, where there is a sudden change in the slope of the land surface.

The more soluble salts of sodium (chloride and sulphate), with minor quantities of other soluble salts, constitute what is commonly known as white alkali. These salts, especially sodium chloride, are widely distributed along marginal lands of the low coastal plains and alluvial fans. They are most concentrated near the numerous lagoons, and the salt concentration rapidly decreases toward the inland. There are a few narrow strips in which the concentration of white alkali is low in the inland between Enfield Green and Morningstar.

Soils affected by black alkali become puddled and impervious to water. Their naturally good granular structure breaks down, the

soil runs together, and it is impossible to make them productive without expensive chemical treatment combined with copious irrigation and carefully planned drainage.

The map shows three degrees of concentration of alkali salts. The affected areas were mapped on the basis of field observations, and a few representative samples were taken and tested on the electrolytic bridge for percentage of salts present. The locations of samples are indicated on the map by a red dot to one side of which is placed a number in fractional form. The upper number of the "fraction" indicates the percentage of salts in the surface foot of dry soil, and the lower number indicates the average percentage of salts to dry soil for the entire profile. Another number, in parentheses, indicates the depth to which the soil was sampled. Soils shown as weakly affected contain from 0.2 to 0.4 per cent salts, those shown as moderately affected from 0.4 to 1 per cent, and those as strongly affected from 1 to more than 3 per cent. In the weakly affected areas most crops will show a somewhat decreased yield, and some trouble may be experienced with getting seeds to germinate and with the dying of young and tender plants. In moderately affected areas there are likely to be large barren spots and much plant loss. Only highly salt-tolerant crops will produce on these lands. Some grasses will do fairly well, but most cultivated crops will give trouble. Coconuts will usually grow fairly well. The strongly affected areas will ordinarily be devoid of all economic crops.

Doubtless some areas of soil affected by alkali are not shown on the map, and doubtless, also, there are areas of unaffected land included in those parts shown as being affected. Only a carefully conducted detailed survey would bring out all the facts regarding the soils and alkali conditions.

SOILS AND THEIR INTERPRETATION

The island of St. Croix is well within the Tropical Zone. It is far enough north, however, to be almost constantly fanned by the trade winds. Low islands in the trade-wind belt have low rainfall, and many of them are desertlike. Where mountains occur on the islands, however, the warm winds rise sufficiently to become cool enough to drop part of their moisture. St. Croix Island has two low chains of mountains running east and west, which are sufficiently high to cause enough precipitation to support agriculture over much of the island. The highest recorded mean annual rainfall is, however, only about 52 inches. The lowest recorded mean is nearly 39 inches, but it is almost certain that some places in the eastern end of the island receive an average of less than 20 inches annually. This is an estimate based on observations by residents and on the character of the vegetation in that part of the island. In the Temperate Zone an average rainfall equal to the recorded minimum of St. Croix Island would constitute a humid climate. In the Tropics, however, and especially in the trade-wind belt, the climate under a 39-inch rainfall is semiarid.

With the foregoing facts in mind one would expect the mature soils of St. Croix Island to be marked by accumulations of the carbonates of calcium and magnesium somewhere between the surface

and parent material. Such is the case, with the exception of a few small and restricted areas in the moist region near Annaly, which were too small to be shown on a reconnaissance map.

Mature soils occupy only a small part of the total area of the island. They occur on old alluvial fans and colluvial slopes and as residuum from the volcanic rocks of the highlands. Probably 60 per cent of the agricultural lands are rendzinas [5] which are fairly shallow dark-colored soils lying on soft, chalky, or marly lime deposits or on hard or moderately soft limestones. The highly calcareous parent materials have retarded normal soil development. Between one-third and one-half of the total area of the island is covered with soils which are immature in stage of development, owing mainly to the steepness of the hills and mountains on which they occur. Most of these incipient soils consist of dark-colored surface soils, ranging from a few inches to a foot or more in thickness, lying directly on the rotten parent rock. The soils on gentler slopes have developed a thin heavy subsoil layer which in spots is underlain by slight accumulations of lime. These soils do not, however, show the depth of weathering and thickness of subsoil horizons characteristic of the normal mature soils of the region.

Since the entire Island falls within a climatic zone that has caused the formation of soils which are closely related to each other it seems most logical to discuss the individual soil series in the natural groups in which they fall. The factors, other than climate, which have contributed to soil formation and have produced the soil characteristics, are vegetation, parent material, and, in places, certain soluble salts. After climatic influences have been considered, the character of the parent material plays the most important rôle in the determination of the natural soil groupings of St. Croix Island. The other factors seem to be of secondary importance. Owing to the effects of the parent materials in parts of the island, the effects of salts in other parts, and the youthfulness of the deposits of soil materials in still other parts, there are few, if any, areas of normal mature soils. The soils will be discussed under the same four groups as those under which they were discussed in the section on Soils and Crops.

The soils covering much of the strip of territory from Little Princess and Vagthus Point to Westend Saltpond and Frederiksted owe most of their characteristics to the soft marls and limestones from which they are derived. These soils have been placed in group 1 and in soil terminology are classed as rendzinas. They are rich in humus, except where hereafter noted, are fairly thin, and have little or no subsoil, or B horizon, development. The group includes the Fredensborg, Diamond, Sion, Coakley, Aguilita, and Hesselberg soils.

Following are descriptions of the more important soils, with briefer mention of those which are less important.

A sample of Fredensborg clay, taken about three-eighths mile southeast of Slob, showed the following layers: From 0 to 10 inches, very dark gray calcareous plastic clay. The clay is very granular and falls apart into medium-sized angular grains when dry or moist.

[5] Soils developing under the influence of highly calcareous parent material and not yet advanced beyond a very early stage of development.

The dark color is caused by a large content of organic matter. From 10 to 14 inches, gray-white, rust-colored, and yellow mottled granular calcareous clay which is very plastic when wet. Many dark and light worm casts occur in this horizon. From 14 to 36 inches, very friable porous yellowish-white marly or soft limestone.

This soil occurs in low broad flats between limestone hills. Natural surface drainage ranges from fair to poor but, owing to the porous parent material, farmers experience very little trouble from poor drainage. A few areas near the seacoast contain sufficient salt accumulations to interfere with crop production.

Diamond clay differs from Fredensborg clay in being somewhat deeper and in having a surface soil which is grayish brown instead of nearly black. It is somewhat less plastic in the upper two horizons and seems to contain much less organic matter. Granulation in the two soils is about the same. This soil occurs in slightly better drained positions than Fredensborg clay. The deep phase of this soil has a considerably thicker solum than the typical soil.

The soil structure and parent materials of the Sion soils are very much like those of the Fredensborg and Diamond soils, but their color is medium brownish gray or dark brownish gray, with gray predominating. Unlike the Fredensborg and Diamond soils, the Sion soils are friable from the surface downward, even very soon after heavy rains.

The Coakley soils are much like the Sion soils except that they are dark colored and, at a depth of about 10 inches, lie on a semiindurated chalk deposit. This chalk is simply another form of the different Tertiary limestones of the region.

The Aguilita soils are derived from the harder layers of the Tertiary limestones. They usually occur on hills where natural drainage is excessive, but they are able to hold sufficient moisture to support fairly good crops. The surface soils are dark gray or dark grayish brown, are granular, like the other rendzinas, and differ greatly in thickness, according to whether the slopes on which they lie are concave or convex. In most places a soft marly transitional layer occurs between the dark-colored A horizon and the hard limestone which lies at a depth ranging from 1 or 2 inches to 3 or 4 feet. The shallow phase of Aguilita clay has almost no soil covering the limestone, whereas the steep phase is very stony.

Hesselberg clay is the one soil of this group with a red hue. It has a 5-inch reddish-brown medium granular stiff clay surface soil and a 7-inch brownish-red granular clay subsoil overlying fairly hard limestone which contains cracks filled with red clay. The soil is very stony and calcareous throughout.

As there is little, if any, strictly virgin land on St. Croix Island, it is difficult to say what kind of natural vegetation covered it originally. At the present time abandoned lands of group 1 grow up to a scrubby growth of thorn bushes, small trees, and some cacti. Lands not too densely covered by these bushes have, in addition, a growth of native and introduced grasses.

Bordering the strip of soils of group 1, just described, overlapping it in many places, and extending out from the mountains in alluvial fans elsewhere, are strips and patches of soil which comprise group 2. Soils of the Hope, Santa Isabel, Granard, Glynn, Cornhill,

Lavallee, Barrancas, Orangegrove, and San Anton series are included in this group. The first six are solonetzlike in character and contain more or less lime in the subsoil. Much of the lime has accumulated from the carbonation of the calcium compounds of the basic igneous minerals of the parent materials and their subsequent translocation from the surface by percolating waters. Undoubtedly some of the lime may also have come directly from the alluvial materials derived from the Tertiary limestones. This latter will hold true at least in the western and southwestern parts of the island. Sufficient quantities of sodium chloride have either been carried up from the sea by heavy storms or washed from the parent rocks to unite with the carbonates in forming small quantities of sodium carbonate in the soil. This compound is formed at the places where the sodium chloride may meet the accumulated lime, in other words, in the upper part of the subsoil. It has the effect of deflocculating the subsoil, causing the clay to puddle and form an almost impenetrable layer. Subsequent leaching may remove the carbonates, but the very heavy impenetrable layer remains for a long time. When this layer dries out it breaks into rough hard columns which will withstand much weathering in exposed cuts. In numerous places, which are shown on the map, there are still traces of sodium carbonate in the soil. The hard layer, or claypan, is very troublesome to farmers because of the difficulties it offers to cultivation and to root penetration. A special variety of cane, with sharp-pointed roots which pierce the claypan, was developed on St. Croix Island.

In the following descriptions it will be noted that the soils of some series have developed heavier and harder claypans than those of others.

A sample of Hope clay, taken one-sixteenth mile east of Hope, showed some accumulation of soluble salts in the lower layers. From 0 to 5½ inches the soil material is dark gray-brown finely cloddy slightly calcareous very stiff clay; from 5½ to 18 inches it is a very heavy black columnar slightly calcareous claypan which is exceedingly stiff and intractable; from 18 to 30 inches it is olive-drab, mottled with gray, somewhat granular calcareous stiff clay; and from 30 to 40+ inches it is yellow and olive-drab clay containing some iron and manganese concretions. This layer is very calcareous and plastic, and it contains some soluble salts. It is underlain by gravelly alluvium.

The Hope soils lie on broad, flat, gently sloping plains that, at present, are for the most part covered with pasture grasses or planted to sugarcane. In many places Hope soils contain large quantities of gravel of tufaceous or shaly origin. Comparatively large areas of this soil are subject to slight or moderate accumulations of salts.

A sample of Santa Isabel clay, taken one-eighth mile south of Enfield Green, showed the following profile: From 0 to 6 inches, brownish-gray medium-granular calcareous clay which is stiff when wet; from 6 to 10 inches, heavy finely cloddy very stiff olive-drab calcareous clay containing hard angular lime concretions; from 10 to 70 inches, brownish-yellow sticky plastic clay containing some limy spots, in which the interstitial soil is very calcareous; and from 70 to 80+ inches, yellowish-brown or reddish-yellow gravelly fine sandy clay loam containing lime concretions.

Santa Isabel clay occupies positions similar to those occupied by Hope clay. It shows evidence of salt accumulation in many places. The alluvium from which it is derived contains more or less limestone mixed with volcanic alluvium.

Granard clay is much like Santa Isabel clay except that it is somewhat darker and contains no hard lime concretions. The lime occurs in large silty spots. This soil is derived from mixed volcanic fragments and limestone of Tertiary age. These materials were laid down just before the great mass of the limestones of St. Croix Island and have since been exposed by erosion.

Glynn clay loam lies between areas of Hope clay and the mountains. The claypan has developed but slightly in this soil, and the soil is much lighter colored than the Hope soils. The parent material consists almost entirely of old alluvial gravel and silt washed out from the volcanic uplands. The soil is younger than Hope clay, but it has a slight accumulation of lime in the subsoil.

A sample of Cornhill clay loam, taken just east of Cornhill, indicates a profile as follows: From 0 to 4 inches, dark gray-brown friable fine-granular heavy loam or light clay loam; from 4 to 10 inches, dark-gray or nearly black gravelly clay which is cloddy and stiff, and which puddles when wet; from 10 to 16 inches, light yellowish-brown cloddy plastic calcareous clay; from 16 to 30 inches, yellowish-brown or reddish-yellow plastic clay, mottled with gray-white lime accumulations, which is cloddy when dry; and from 30 to 60+ inches, reddish-yellow or yellow-brown gravelly calcareous clay loam. At this place there was a slight accumulation of salts in the lower three layers, but in many places soluble salts are absent, or present only in minute quantities.

The vegetation on this type of soil consists of thorny bushes, cacti, and grasses. On land that has not been kept clear these bushy growths have become so dense that it is impossible to pass through without cutting one's way with a machete.

A sample of Lavallee clay loam, taken one-fourth mile southeast of Lavallee, shows the following profile: From 0 to 15 inches, brown coarsely granular somewhat stiff noncalcareous gravelly clay loam; from 15 to 39 inches, reddish-brown or brownish-red heavy gravelly clay which is stiff when moist and hard when dry; from 39 to 53 inches, light-brown stratified gravelly loam; from 53 to 83 inches, coarsely mottled red, brown, yellow, and gray limy gravelly clay loam; and from 83 to 113 inches, similar material to that in the above layer, with yellow mottles predominating. Gravelly layers occur in both the upper and lower parts of this layer. The soil material is puddled and slick when wet.

This soil occurs on deep alluvial deposits, chiefly along the northwestern coast of the island, from Sugar Bay to Ham Bay, and on the southeast coast, from Grass Point to East Point. Minor variations from the typical soil are noted in the section on Soils and Crops.

The natural vegetation on Lavellee clay loam was originally about the same as that on the Cornhill soils. Pasture grasses occupy much of the land at present.

Barrancas clay is a dark-gray or nearly black waxy clay with a gray and rust-colored mottled clay subsoil. It lacks the definite well-developed heavy horizon of the solonetzlike soils described, but

it is closely associated with those soils. This soil occurs in depressions and is poorly drained except areas that have been ditched. In most places it shows indications of slight accumulations of soluble salts in the upper part of the subsoil and in some places at the surface. The materials from which this soil is derived are a mixture of volcanic and limy water-laid materials.

Orangegrove loam and San Anton loam are both derived from fluvial sediments. Orangegrove loam shows evidence of having been strongly weathered, but typical San Anton loam is of recent deposition. A brief description of each soil follows:

A sample of Orangegrove loam, taken one-fourth mile east and slightly north of Orangegrove from a narrow high stream terrace, shows the following profile: From 0 to 15 inches, brown friable loam of loosely granular or single-grain structure; from 15 to 27 inches, dark gray-brown friable loam with whitish, moldlike spots; from 27 to 40 inches, reddish-yellow granular stiff gravelly clay; and from 40 to 90 inches, stratified old alluvium consisting of light reddish-yellow friable sandy clay loam.

Orangegrove loam contains no visible lime accumulation, but the second and third layers are distinctly alkaline.

A sample of San Anton loam, taken one-fourth mile northwest of Solitude, shows the following profile: From 0 to 7 inches, dark-brown slightly calcareous friable silt loam or loam; from 7 to 18 inches, light yellowish-brown slightly calcareous friable clay loam; and from 18 to 40 inches, dark-brown gravelly slightly calcareous friable loam underlain by alluvial materials which in places contain lime accumulation. The lime accumulation seems to belong to a soil which has been buried under more recent fluvial deposits.

This soil has little or no profile development, owing to its recent deposition, but it is so interlaced with mature soils derived from older alluvium that it is difficult, in mapping, to separate the old from the more recent deposits. One is sure, therefore, to find that San Anton loam, as mapped, includes many small areas of the other members of this group and vice versa.

Group 3 includes soils derived from the volcanic oldland materials which occur in two large areas corresponding to the mountainous areas of the island.

Descalabrado clay and its steep phase occupy much of this oldland area. This soil has a solum ranging in thickness from a few inches to about 2 feet and averaging about 16 inches. The surface soil consists of dark grayish-brown coarsely granular moderately stiff clay, from 8 to 12 inches thick. The 4 to 6 inch subsoil layer is brown or olive-drab finely cloddy clay. The parent material consists of rotten tuff or tufaceous shales which in many places contain streaks and seams of soft lime accumulation at their point of contact with the solum. The lime deposits are lacking in many places in the moist region around Annaly, but the soil retains a high pH value, nevertheless. Near Annaly, on some of the very small flat areas, are a few spots in which the subsoil is lightly mottled with red, yellow, and gray, giving evidence of very small spots having imperfect drainage. Aside from these small spots the soil has good or excessive natural drainage. The soils mapped in the Descalabrado series in the eastern part of the island seem to

have somewhat more lime accumulation than those in the western part.

Descalabrado clay, steep phase, occupies the steep mountainous slopes of the island. These soils are similar to the typical soil but are thinner, and in many places rocks outcrop. Included on the map with this steep soil are large areas of thin reddish-brown soil having neutral or slightly alkaline reaction. These areas are fairly common near the northern coast of the island, from Barron Bluff to Ham Bay, and in spots on that part of the island between Seven Hills and East Point. Incomplete field evidence seems to indicate that this local variation in color is probably caused by differences in the rocks. For example one very small unmapped area of serpentinelike rock near Lavallee was covered by a thin somewhat red soil. Trap rock in other places was covered by red soils in spots. The steep phase of Descalabrado clay also includes steep areas of the shallow phase of Descalabrado clay.

The natural vegetation on this soil is chiefly native forest trees and underbrush. Small trees, thorn bushes, and cacti cover this soil in the eastern part of the island.

Parasol clay loam is very similar in morphological features to the chernozem soils which occur in the Great Plains area of the United States and the Russian steppes.

A sample of this soil, taken five-eighths mile south of Parasol shows the following profile: From 0 to 10 inches, dark-brown coarsely granular, friable when dry but stiff when moist, clay loam having excellent tilth; from 10 to 20 inches, black, coarsely granular clay which is stiff when moist, has excellent tilth, and is high in organic matter; from 20 to 35 inches, mottled dark-gray and yellowish-brown clay loam, in which the mottling is caused by organic soil mixed with rotten tufaceous materials; and from 35 to 50 inches, brownish-yellow clay loam consisting of highly decayed volcanic rocks. In many places the upper part of this layer is highly impregnated with soft accumulated lime.

In this soil as in many others, the zone of lime accumulation is variable, being entirely lacking in some places and very thick in others, although the areas may be very closely associated. All of this soil observed was devoted to cultivated crops or to pasture grasses.

TABLE 4.—*pH determinations of soils on St. Croix Island, Virgin Islands*[1]

Sample No.	Soil type	Depth	pH	Sample No.	Soil type	Depth	pH
		Inches				*Inches*	
600107	Hesselberg clay	0–5	7.85	600145	Lavallee clay loam	0–15	7.29
600108	do	5–12	8.05	600146	do	15–39	7.63
600109	do	12–15+	8.27	600147	do	39–53	7.72
600110	San Anton loam	0–7	7.92	600148	do	53–83	8.24
600111	do	7–18	8.09	600149	do	83–113	8.69
600112	do	18–40+	8.27	600154	Cornhill clay loam	0–4	7.40
600130	Descalabrado clay	0–8	7.21	600155	do	4–10	6.76
600131	do	8–13	7.83	600156	do	10–16	8.72
600132	do	13–19	8.09	600157	do	16–30	8.63
600133	do	19–48+	8.29	600158	do	30–60+	8.27
600134	Orangegrove loam	0–15	6.57				
600135	do	15–27	8.31				
600136	do	27–40	8.30				
600137	do	40–90+	7.62				

[1] Determinations made by E. H. Bailey.

Group 4 includes two soil types, or, more strictly, soil materials of recent deposition. These soils are Serrano clay loam and Jaucas sand. Their characteristics are described in a preceding section on Soils and Crops.

Table 4 shows the reactions, in terms of pH values, of various soils of the island, which were sampled. Determinations were made by the electrometric method, using the hydrogen electrode.

SUMMARY

St. Croix, the largest of the American Virgin Islands, has a subhumid or semiarid tropical climate and is almost constantly fanned by the warm trade winds. Somewhat more than half of its 82 square miles of land surface is mountainous or hilly.

The agricultural lands are situated chiefly in the central part of the southern side of the island. In the past, the chief crop grown was sugarcane which was manufactured into sugar, molasses, and rum. During recent droughts and owing to current low prices of sugar, agriculture has languished almost to the vanishing point. Rum has not been commercially manufactured during recent years because of the passage of the eighteenth ammendment to the Constitution. Much land is being devoted to pasture for cattle which at present supply a moderately large export item.

The soils have been classified into 20 soil types and 5 phases of types, according to the usual Bureau of Chemistry and Soils methods. Members of one group of these soils comprising 7 soil types and 3 phases are derived from limestones, some of which are soft and some hard. These soils are moderately shallow but in general very fertile so far as chemical elements of fertility are concerned. A second group of 9 soil types includes soils derived from alluvial deposits. All but 2 of these have definite lime accumulations in the subsoils, and all but 3 have a heavy claypan in the upper part of the subsoil. Soils of a third group, including 2 soil types and 2 phases, are derived chiefly from volcanic rocks. They are dark colored and very fertile where not too shallow and too steep for cultivation. They occupy at least one-half of the island. The fourth group, including 2 soil types, represents lagoon and beach deposits of low agricultural value. Several areas of soil, especially near the lagoons and sea margins, are impregnated with soluble salts and black alkali.

The arable soils of the island are, in general, fairly fertile and are well adapted to a large variety of fruits, vegetables, cotton, and sugarcane in years when the precipitation is sufficient. The steeper and stonier areas are well adapted to tropical forest trees and to pasture grasses. Most of the unused lands are covered with a dense growth of thorny brush and cactus.

If sugarcane culture continues to decline, other agricultural pursuits will have to take its place. It is recommended that especial attention be paid to subsistence crops, cattle, dry beans for the Puerto Rican market, and tropical fruits. Vegetables for the winter markets of the United States may also prove profitable.

Lands are owned chiefly in large estates. Labor is performed mainly by negroes, and farm wages are low. The buildings on the estates, with a few exceptions, are badly run down or in ruins. The island is well supplied with churches and schools and has a good road system that reaches most parts.

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Areas surveyed in the Virgin Islands, shown by shading

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TECHNICAL BULLETIN NO. 314 AUGUST, 1932

FACTORS AFFECTING THE DEVELOPMENT OF THE AECIAL STAGE OF PUCCINIA GRAMINIS

BY

RALPH U. COTTER

Assistant Pathologist
Formerly with the Division of Cereal Crops and Diseases
Bureau of Plant Industry

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.
IN COOPERATION WITH THE MINNESOTA AGRICULTURAL EXPERIMENT STATION

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CONTENTS

	Page
Introduction	1
Historical review	2
Methods and materials	3
Experimental results	4
Susceptible and resistant varieties of Berberis	4
Germination of teliospores	10
Relation of age and freezing of teliospores to infection of barberries	13
Relation of temperature to infection of barberries	13
Influence of light on infection of barberries	15
Time required for infection of *Berberis vulgaris* with teliospores of *Puccinia graminis secalis*	16
Experimental results—Continued.	
Susceptibility of barberry leaves of various ages and species	21
Effect of length of incubation period on infection of barberries	24
Effect of temperature and moisture on development of aecia	24
Effect of freezing on rusted barberry	25
Effect of light on development of aecia	28
Conditions for liberation of aeciospores	28
Viability of aeciospores	30
Physiologic forms within a single aecium	31
Discussion	34
Summary	36
Literature cited	37

INTRODUCTION

The aecial stage of *Puccinia graminis* Pers. on barberry furnishes a tremendous amount of primary inoculum for infecting the grainfields of the upper Mississippi Valley. It has been shown clearly that very destructive local epiphytotics and widespread regional epiphytotics result from aeciospores disseminated from barberries. For this reason a barberry-eradication campaign was begun in 1918 by the United States Department of Agriculture in cooperation with the following States: Colorado, Illinois, Indiana, Iowa, Michigan, Minnesota, Montana, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin, and Wyoming.

[1] Presented to the faculty of the graduate school of the University of Minnesota as a thesis in partial fulfillment of the requirements for the degree of doctor of philosophy. Cooperative investigations between the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and the Agricultural Experiment Station of the University of Minnesota.

[2] Since July 1, 1930, with the Division of Barberry Eradication, Bureau of Plant Industry. Acknowledgment is made to E. C. Stakman and J. J. Christensen for helpful suggestions during the progress of this work, and to M. N. Levine for valuable suggestions in the preparation of the tables and in verifying the identification of many of the physiologic forms of *Puccinia graminis tritici* obtained from aeciospores. The writer is indebted to A. H. Blakeslee, of the Carnegie Institute for Experimental Evolution, for the *Berberis vulgaris atropurpurea* parent and the hybrids between *B. thunbergii* and *B. vulgaris atropurpurea*.

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From 1918 to 1927, inclusive, approximately 16,000,000 bushes, sprouts, and seedlings were found and destroyed in these States.[3] In 1927, 10 years after the campaign started, 1,688,554 bushes, sprouts, and seedlings were found. During May and June of each year a large proportion of the remaining bushes were rusted. One heavily rusted barberry bush may bear about 70,000,000,000 aeciospores at one time (*15*).[4]

In determining the potential destructiveness of the rust produced on these bushes it is necessary to take into consideration the susceptible and resistant varieties of Berberis and Mahonia, the factors affecting infection of the bushes, subsequent development of the rust, the amount of inoculum produced under certain conditions, the liberation and dissemination of the aeciospores, the vitality and viability of the spores, and the infection of grains and grasses by the aeciospores. A study of the aecial stage, therefore, is extremely important from the standpoint of ascertaining the factors affecting its rôle in initiating rust epiphytotics.

Barberries, however, probably serve not only as a source of inoculum but also as a breeding ground for new parasitic strains or physiologic forms. It has been known for some time that the sexual process of the rusts initiates the aecial stage of the life cycle. It seems entirely probable, therefore, that different varieties and physiologic forms may hybridize on the barberry and produce new parasitic entities. Color is lent to this supposition by Craigie's (*4*) recent demonstration that *Puccinia graminis* is heterothallic. The fusion of two strains of opposite sex is prerequisite to the formation of aecia; hence it seems a foregone conclusion that dikaryophytes with new parasitic capabilities probably are produced on barberries. The work done by Allen (*1*) and Hanna (*8*) along these lines had not been published when the writer was preparing manuscript for this publication. Waterhouse (*19*), Newton, Johnson, and Brown (*14*), and Stakman, Levine, and Cotter (*17*) have adduced recent evidence to show that new physiologic forms of *P. graminis tritici* have been artificially produced on the barberry by crossing varieties of stem rust and physiologic forms within the variety. It is essential, therefore, to a complete understanding of the present habits and the possible future development of forms of stem rust to investigate this phase of the problem also. For these reasons the writer undertook a comprehensive investigation of the factors affecting the development of the aecial stage of *P. graminis*.

HISTORICAL REVIEW

The relationship between the common barberry and stem rust was suspected as early as the seventeenth century, or possibly even earlier. It is said that a law requiring the eradication of the bush was passed in Rouen, France, in 1660. It was known definitely that laws requiring its eradication in some of the colonies were passed long before the Revolutionary War. It was not, however, until late in the eighteenth century or the beginning of the nineteenth that definite experiments were made to determine the exact relationship between barberries

[3] HUTTON, L. D., and BARINGER, J. W. ANNUAL REPORT OF THE BARBERRY ERADICATION CAMPAIGN, 1927, WITH SUMMARIZED RESULTS FOR 1918–1927, INCLUSIVE. U. S. Dept. Agr., Bur. Plant Indus., Off. Cereal Crops and Diseases Mimeographed Pamphlet. 31 p., illus. February, 1928.

[4] Italic numbers in parentheses refer to Literature Cited, p. 37.

and rust. According to Cobb (*3*), Joseph Banks suggested in 1805 the possibility that the rust on barberry and the rust on wheat belonged to the same species. In the period from 1807 to 1816, Schoeler, according to Freeman and Johnson (*7*), planted small grains around barberry plants and found that oats and rye were in danger of destruction by rust when growing near them. In 1816 he made rather crude but effective inoculations by rubbing rusted barberry leaves on rye plants moist with dew. Schoeler marked the plants and about five days later observed that they were heavily rusted, whereas those elsewhere in the field were free from rust. According to Freeman and Johnson (*7*), in 1818 a German farmer gathered the dust that fell from the cups on barberry leaves and took it to a far distant rye field where there were no barberries and placed it on some of the plants. Within five or six days rust appeared on these plants but was not evident elsewhere in the field.

It was not until 1852, however, that the genetic relationship between the so-called summer rust, Uredo, and the autumn rust, Puccinia, was demonstrated by Tulasne (*7*). He showed also that the teliospores would not germinate until the spring following the fall in which they were formed. It remained for de Bary to show in 1865 (*7*) that barberries would become infected when inoculated with teliospores and that grains would become infected when inoculated with aeciospores. De Bary's results have been repeated and confirmed so often that there is no question as to the genetic relationship of the rust on the barberry and that on grains and grasses. De Bary's discovery immediately stimulated more detailed observations regarding the responsibility of barberries in initiating epiphytotics of stem rust.

In 1918 an extensive barberry-eradication campaign was undertaken in the 13 grain-growing States in the upper Mississippi Valley in the United States. This activity immediately created a demand for information regarding the susceptibility of different species and varieties of Berberis and for detailed information on the factors affecting the development of the aecial stage in general. Stakman and Levine compiled in 1923 [5] a list of susceptible and resistant barberries, and this was followed by supplementary lists by Melander and by Melander and Lambert in 1923 and 1924.[6]

The writer began a detailed study of the susceptibility of various species and varieties of barberry in 1925. Further facts regarding the historical development and knowledge concerning the aecial stage of the rust will be found in the body of this bulletin in connection with the particular experiments to which they apply.

METHODS AND MATERIALS

In the barberry-eradication campaign it was found necessary to specify definitely the species and varieties of barberry that were susceptible to rust and that therefore should be placed in the list of quarantined species. Inquiries have come in from time to time concerning the susceptibility of certain species, but unfortunately no information was available regarding many species grown in botanical gardens, arboreta, private estates, and parks. The publication by Stakman

[5] STAKMAN, E. C., and LEVINE, M. N. A PARTIAL REPORT ON THE SUSCEPTIBILITY AND RESISTANCE OF BERBERIS AND RELATED GENERA TO STEM RUST. Cereal Courier [Office of Cereal Crops and Diseases] 15(24): 278–287. Sept. 30, 1923. [Mimeographed.]

[6] MELANDER, L. W. STUDIES OF THE RELATION OF BERBERIS SPECIES TO PUCCINIA GRAMINIS PERS. [Unpublished thesis, University of Minnesota. 1924.]

and Levine in 1923 [7] of a list of susceptible and resistant species helped to clear up the doubt in many cases, but there were still many species of barberry whose reaction to rust was unknown. Some barberries could not be condemned for destruction by the workers in the barberry-eradication campaign because the question of their susceptibility to rust had not been settled. These plants were in some cases a potential menace to grainfields, for it was possible that the barberries might rust shortly after the visit of the barberry field men and might broadcast inoculum over the grainfields before it was found that the plants of that particular species rusted and should be removed. To procure information on this subject, the writer undertook a greenhouse inoculation study of as many species, varieties, and hybrids of Berberis as were obtainable.

The following methods were used in inoculating barberries: (1) A few drops of a suspension of teliospores in water were placed on the young leaves or shoots of the barberry with a loop needle. The plants were then kept 48 hours in a moist chamber. (2) When it was desired to secure heavy infection on all parts of the plant, heavily rusted straw was placed on wire screens supported above the plants to be inoculated. The incubation period with this method was usually 72 hours, although it was reduced to 24 hours with good results when the telia had been presoaked in water 12 to 24 hours. After incubation the plants were placed on the greenhouse bench in the evening in order to avoid solar injury to the tender tissues. Pycnia usually appeared about the fifth or sixth day.

The rust varieties used in the experimental work were *Puccinia graminis tritici* (Pers.) Eriks. and Henn. and *P. graminis secalis* (Pers.) Eriks. and Henn. Five different collections of *P. graminis secalis* were used in the various phases of the work.

Most of the barberries tested for susceptibility were sent to University Farm, St. Paul, Minn., from Bell, Md., by B. Y. Morrison, of the Bureau of Plant Industry, United States Department of Agriculture. A smaller number was obtained from Highland Park, Rochester, N. Y., and others came from unknown sources. The common barberries used as checks in most of the experiments were supplied by L. W. Melander, in charge of barberry eradication in Minnesota.

The degree of infection was necessarily based on the individual barberry leaf, as there were not always large numbers of young leaves on the plants when inoculations were made. When only a single pycnium occurred on a leaf the infection was designated as very light; when there were 2 to 4 on a single leaf it was designated as light; 5 to 10 pycnia on an individual leaf indicated moderate infection; if the pycnia exceeded 10 in number the infection was designated as heavy; and when pycnia on a leaf were numerous and nearly confluent the infection was considered very heavy. Although not perfect, this scale has been found to satisfy the requirements of the work.

EXPERIMENTAL RESULTS

SUSCEPTIBLE AND RESISTANT VARIETIES OF BERBERIS

In Table 1, which is a compilation of the lists of Stakman and Levine, Melander, Melander and Lambert, and Cotter, are listed those species and varieties of Berberis whose susceptibility to *Puccinia graminis* is known.

[7] STAKMAN, E. C., and LEVINE, M. N. Op. cit. (See footnote 5.)

TABLE 1.—*Species and varieties of Berberis known to be susceptible to Puccinia graminis, as compiled by Stakman and Levine, Melander, Melander and Lambert, and Cotter* [1]

STAKMAN AND LEVINE, 1923

No.	Host	Source of information			Degree of infection
		Original observations		Literature references [2]	
		Artificial inoculation	Natural infection in field		
1	Berberis aetnensis Presl			Saccardo; Sydow	
2	B. alesuthensis Hort		+		
3	B. altaica Pall			Saccardo; Klebahn	
4	B. amurensis Rupr	+	+	Saccardo; Sydow; Jaczewski; Klebahn.	Normal.
5	B. angulosa Wall		+		
6	B. aristata DC	+	+	Bolley; Klebahn; Saccardo; Sydow.	
	(B. coriaria Royle)			Butler and Hayman.	
7	B. asiatica Roxb			Sydow	
8	B. atropurpurea Regel		+	Klebahn	
9	B. brachybotrys C. Gay			Saccardo	
	(B. brachybotrydis C. Gay)			Sydow	
10	B. bretschneideri Rehd		+		
11	B. brevipaniculata C. Schneid	+			Moderate.
12	B. buxifolia Lam			Sydow	
13	B. canadensis Mill	+	+	Bolley; Klebahn; Saccardo; Sydow.	Heavy.
	(B. caroliniana Loud.)		+	Saccardo; Sydow	
	(B. fischeri Hort.)		+	Saccardo	
14	B. coryi Veitch (B. wilsonae subcaulialata Schn.).	+			
15	B. crataegina DC		+		
16	B. cretica L		+		
17	B. declinata Schrad			Arthur	
18	B. declinata oxyphylla C. Schneid		+		
19	B. diaphana Maxim	+			Moderate.
20	B. dictophylla Franch	+			Do.
21	B. durobrivensis C. Schneid	+			
22	B. emarginata Willd		+	Bolley	
	(B. vulgaris emarginata Gord.)				
23	B. emarginata britzensis C. Schneid		+		
24	B. fendleri A. Gray		+	Arthur	
25	B. fremontii Torr		+		Moderately resistant.
26	B. fuchsioides Hort		+		
27	B. haematocarpa Wooton		+		
28	B. heteropoda Schrenk		+	Jaczewski; Sydow	
29	B. ilicifolia Forst	+	+	Klebahn; Sydow	
30	B. integerrima Bunge			Jaczewski	
31	B. laxiflora Schrad		+		
32	B. leichlinii Hort	+	+		Heavy.
33	B. lucida Schrad	+			
34	B. lycium Royle			Klebahn	
35	B. macrophylla Hort			Saccardo	
36	B. meehanii C. Schneid		+		
37	B. nepalensis (DC) Spreng			Butler and Hayman; Klebahn; Sydow.	
38	B. neubertii Lem		+	Bolley; Klebahn; Saccardo; Sydow.	
39	B. oblonga C. Schneid		+		
40	B. provincialis serrata C. Schneid	+			Moderately resistant.
41	B. pruinosa Franch	+			Do.
42	B. regeliana Koehne		+		
	(B. amurensis japonica Rehd.)		+		
	(B. vulgaris japonica Regel)		+		
43	B. sibirica Pall		+	Arthur; Jaczewski; Saccardo; Sydow.	
44	B. sieboldii Miq	+	+	Klebahn	Heavy.
45	B. sinensis Desf. (B. chinensis Poir.)		+	Arthur; Sydow.	
46	B. stapfiana C. Schneid	+	+		
47	B. subcaulialata C. Schneid		+		

[1] A plus mark (+) in the column entitled "Artificial inoculation" indicates that when greenhouse inoculations on that particular species were made, infection occurred, the variety of inoculum used being unknown unless otherwise stated. A plus mark in the column entitled "Natural infection in field" indicates that plants found growing in the field, in arboreta, or in gardens were found naturally infected. A blank indicates that no inoculations were made on that particular species.

[2] Citations in list of Stakman and Levine. (See footnote 5.)

TABLE 1.—*Species and varieties of Berberis known to be susceptible to Puccinia graminis, as compiled by Stakman and Levine, Melander, Melander and Lambert, and Cotter*—Continued

STAKMAN AND LEVINE, 1923—Continued

No.	Host	Source of information			Degree of infection
		Original observations		Literature references	
		Artificial inoculation	Natural infection in field		
48	B. swaseyi Buckl	+		Arthur	
49	B. thibetica C. Schneid	+			
50	B. trifoliolata Moric	+		Arthur	Moderately resistant.
51	B. umbellata Wall			Butler and Hayman	
52	B. vulgaris L	+	+	Arthur; Bolley; Butler and Hayman; Jaczewski; Klebahn; Saccardo; Sydow.	
53	B. vulgaris alba Weston		+		
54	B. vulgaris asperma Don		+		
55	B. vulgaris atropurpurea Regal		+		
56	B. vulgaris fructoviolacea Hort		+		
57	B. vulgaris lutea Don		+		
58	B. vulgaris macrocarpa Jaeger		+		
59	B. vulgaris mitis Hort			Sydow	
60	B. vulgaris nigra Don		+		
61	B. vulgaris purpurea Hort		+	Sydow et al	Heavy.
62	B. vulgaris sanguinolenta Hort		+		
63	B. vulgaris spathulata Gord. (B. chinensis Poir.).		+		
64	B. vulgaris sulcata Hort	+	+		Moderate.
65	B. vulgaris violacea Willd		+		
66	B. aquifolium Pursh	+		Jaczewski; Sydow	Somewhat resistant.
67	B. diversifolia (Sweet) Steud			Arthur	
68	B. glauca			Arthur; Sydow	

MELANDER AND LAMBERT, 1923

1	B. coryi Veitch	+[3]			
2	B. haematocarpa Wooton	+			
3	B. lucida Schrad	+			
4	B. swaseyi Buckl	+			
5	B. thibetica C. Schneid	+			

MELANDER, 1924

1	B. chinensis Poir	+			
2	B. koreana Palib	+			
3	B. vanfleetii C. Schneid	+			

COTTER, 1925–1931

1	B. acuminata Franch	+			Heavy.
2	B. aemulans C. Schneid	+			Pycnia.
3	B. aetnensis Presl	+		Saccardo; Sydow	Heavy.
4	B. aggregata C. Schneid	+			Moderate.
5	B. aggregata prattii C. Schneid	+			Pycnia only.
6	B. alesuthensis Hort	+[4]	+[5]		Heavy.
7	B. amurensis japonica Rehd. (B. regeliana Koehne).	+[4]	+[5]		Light.
8	B. arvensis Hort	+			Heavy.
9	B. asiatica Roxb	+[6]		Sydow	Heavy; pycnia only.
10	B. atrocarpa C. Schneid	+			Heavy.
11	B. bergmanniae C. Schneid	+			Moderate; pycnia only.
12	B. brachypoda Maxim	+			Moderate.

[3] From this point on, secalis was used as inoculum unless otherwise shown.
[4] First recorded artificial infection, although natural infection was noted previously.
[5] First observed by Stakman and Levine.
[6] The variety of inoculum used was tritici.

TABLE 1.—*Species and varieties of Berberis known to be susceptible to Puccinia graminis, as compiled by Stakman and Levine, Melander, Melander and Lambert, and Cotter*—Continued

COTTER, 1925–1931—Continued

No.	Host	Source of information			Degree of infection
		Original observations		Literature references	
		Artificial inoculation	Natural infection in field		
13	B. californica Jepson	+			Light; pycnia only.
14	B. crataegina DC	+[4]	+[5]		Moderate.
15	B. declinata oxyphylla C. Schneid	+[4]	+[5]		Heavy.
16	B. dielsiana Fedde	+			Light.
17	B. dulcis nana Hort	+			Pycnia; light.
18	B. emarginata Willd	+[4]	+[5]	Bolley and Pritchard	Heavy.
19	B. emarginata britzensis C. Schneid	+[4]	+[5]		Do.
20	B. fendleri A. Gray	+[4]	+[5]	Arthur; Durrell and Lungren.	Moderate.
21	B. fremontii Torr	+[4]	+[5]		Light.
22	B. francisci-ferdinandi C. Schneid	+			Heavy.
23	B. fuchsioides Hort	+[4]	+[5]		Do.
24	B. gagnepaini C. Schneid	+			Pycnia; light.
25	B. gilgiana Fedde	+			Very light.
26	B. heteropoda Schrenk	+[4]	+[5]	Jaczewski; Sydow	Moderate.
27	B. henryana C. Schneid	+			Light.
28	B. hookeri Lem	+			Do.
29	B. hybrida serrata Hort	+			Heavy.
30	B. japonica Spreng. (B. bealei Fort.)	+			Light.
31	B. knightii Hort. (wallichiana var. latifolia) (B. xanthoxylon Hassk.).	+			Do.
32	B. koehneana Schneid	+[7]			Moderate.
33	B. levis C. Schneid. (Bell 149) [8]	+			Light.
34	B. lycium Royle	+	([9], [10])		Moderate.
35	B. meehanii C. Schneid	+	+[5]		Do.
36	B. morrisonensis Hayata	+			Light.
37	B. notabilis C. Schneid	+			Heavy.
38	B. neubertii Hort	+[4]	+[5]	Bolley and Pritchard	Very heavy.
39	B. nevinii A. Gray (Mahonia nevinii Fedde).	+			Heavy.
40	B. oblonga C. Schneid	+[4]	+[5]		Do.
41	B. parvifolia Sprague	+			Light.
42	B. poiretii C. Schneid	+[11]			Do.
43	B. poiretii latifolia C. Schneid	+			Do.
44	B. polyantha Hemsl. (B. aggregata prattii C. Schneid.).	+			Moderate.
45	B. prattii C. Schneid. (B. aggregata prattii C. Schneid.).	+			Do.
46	B. serotina Lange (B. chinensis Poir.)	+			Do.
47	B. sinensis Desf. (B. chinensis Poir.)	+[4]	+[5]	Arthur; Sydow	Light.
48	B. soulieana C. Schneid	+			Do.
49	B. subcaulialata C. Schneid	+[4]	+[5]		Do.
50	B. umbellata Wall	+[4]	+[9]		Heavy.
51	B. vernae C. Schneid	+			Light.
52	B. virescens Hook f		+		Do.
53	B. viridis Hort	+			Moderate.
54	B. vulgaris atropurpurea Regel (B. vulgaris purpurea Bertin)	+[4]	+[5]		Do.
		+[4]	+[5]	Sydow et al	Heavy.
55	B. vulgaris sheyalle Hort	+			Do.
		+[12]			Moderate.
56	B. wilsonae Hemsl. and Wils	+			Heavy.
57	B. wilsonae Hemsl. var. Autumn Cheer.	+			Light.
58	B. wilsonae Hemsl. var. Firefly	+			Do.
59	B. wilsonae Hemsl. var. Sparkler	+			Very light.

[4] First recorded artificial infection, although natural infection was noted previously.
[5] First observed by Stakman and Levine.
[7] Both tritici and secalis used as inoculum.
[8] Number given at U. S. Plant Field Station, Glenn Dale, Md.
[9] Observed by Butler and Hayman.
[10] Observed by Klebahn.
[11] Pycnia only on previous trials.
[12] The variety of inoculum used was poae.

It will be seen from Table 1 that the number of susceptible species and varieties of Berberis far exceeds that of the immune varieties.

The question naturally arises as to whether reaction to rust is correlated with gross morphological characters. In general, those species which are susceptible to *Puccinia graminis* resemble *Berberis vulgaris* somewhat in the size, shape, and texture of the leaves, while those resembling *B. thunbergii* are likely to be resistant. Of course, there are exceptions to this generalization. For example, *B. wilsonae* Hemsl. and Wils. is characterized by small, lanceolate leaves, while *B. vulgaris* has relatively large and oval leaves, but both are quite susceptible to *P. graminis*. *B. hookeri* Lem. (susceptible) differs widely from *B. vulgaris* in leaf texture, the former possessing leaves that are hard and leathery in texture when mature, while those of *B. vulgaris* are soft and more or less tender. The leaves of *B. neubertii* Hort. (very susceptible) are about 2 inches wide and 3 inches long, while those of *B. vulgaris* are less than 1 inch wide and about 1½ inches long. As a general rule, however, there seems to be a close correlation between the *B. vulgaris* type of leaf and susceptibility to *P. graminis*.

Certain indications have pointed out that while the plants of a botanical species of Berberis may be phenotypically similar, they may be genotypically dissimilar with respect to susceptibility to *P. graminis*, or there may be a very narrow range of conditions within which infection may take place on certain species. In one shipment of *B. hookeri* there were 12 plants. Within a period of two years 18 inoculations were made on these plants and only one aecium resulted, but this lone aecium was perfectly normal in all respects. Other species that may not be homozygous for rust resistance are *B. aristata* DC., *B. brachypoda* Maxim., *B. gilgiana* Fedde, and *B. soulieana* C. Schneid.

In Table 2 are given those genera and species of the Berberidaceae that did not rust when artificially inoculated in the greenhouse. The variety of rust used in the inoculations is given, the term "variety" here being used to designate one of the group forms of *Puccinia graminis*. The number of trials for each species is the total of the inoculations made by Stakman and Levine plus those of the present author. All the species here listed are not to be considered definitely immune, since further inoculations may prove that some of the species, except *B. thunbergii* DC. or its varieties, are susceptible. The first list of immune barberries, made three years ago, contained more than double the number presented in Table 2, so conclusions as to resistance or immunity of any species, based on a small number of negative results should not be regarded as of great value.

TABLE 2.—*Genera and species of Berberidaceae that did not rust as a result of artificial inoculation with teliospores of five varieties of Puccinia graminis*

Genera and species	Number of inoculations with varieties of P. gramini				
	Agrostidis	Avenae	Poae	Secalis	Tritici
Berberis beaniana C. Schneid.	0	0	0	11	0
B. concinna Hook.	0	0	0	7	0
B. edgeworthiana C. Schneid.	0	0	0	12	0
B. ottawensis C. Schneid.	0	0	1	5	0
B. potaninii Maxim.	0	0	1	7	1
B. repens Lindl.	0	0	0	18	34
B. stenophylla Mast.	0	0	0	11	1
B. thunbergii DC.	0	4	0	21	7
B. thunbergii atropurpurea Hort.	12	0	14	248	36
B. thunbergii maximowiczii (Regel) C. Schneid.	0	13	0	24	10
B. thunbergii minor Rehd.	0	0	0	3	0
Caulophyllum thalictroides (L.) Michx.	0	11	0	5	19
Diphylleia cymosa Michx.	0	1	0	2	0
Jeffersonia diphylla (L.) Pers.	0	0	0	0	2
Podophyllum peltatum L.	0	0	0	0	2

A few of the barberries, previously listed as susceptible, exhibit what may be a physiologic rather than a morphologic resistance, as probably is the case with the majority of those barberries now considered or proved immune. For example, mature leaves of *Berberis asiatica* are rather leathery, but the young leaves are soft and smooth. When this species was inoculated with teliospores of the *tritici* variety of *Puccinia graminis*, a heavy pycnial infection resulted, but no aecia formed. (See pl. 5.) When examined with a hand lens, a single outgrowth, possibly an abortive aecium, was sometimes seen on the dorsal surface of the leaf. On this species the fungus was able to penetrate the leaf and produce the initial infection, but for some reason was prevented from completing the normal development of the rust.

The same phenomenon—heavy pycnial infection with subsequent production of a few or no aecia—is frequently seen in varying degrees on the compound-leaf barberries, the Mahonias of some authors. *Berberis fremontii* Torr., *B. haematocarpa* Wooton, *B. nevinii* A. Gray, *B. swaseyi* Buckl., and *B. trifoliolata* Moric. are infected without great difficulty. Aecia, however, fail to develop in about half the number of infections. With *B. aquifolium* Pursh and *B. californica* Jepson, infection has been difficult to secure, and only a few pycnia usually are present, with no aecia. In Europe, however, infection has been reported on the fruits of *B. aquifolium*, and in the United States and Canada on the leaves of *B. aquifolium* in a few cases.

Although those species and varieties of Berberis that resemble *B. vulgaris* seem in general to be susceptible to rust and those of the *B. thunbergii* type resistant, there is some observational evidence that hybrids between the two sometimes may have the susceptibility of *B. vulgaris* and many of the morphologic characters of *B. thunbergii*. It seemed worth while, therefore, to study the rust reaction of hybrids between these two species in order to ascertain whether there is a correlation between morphologic characters and susceptibility to rust. The results are summarized in Table 3.

TABLE 3.—*Reaction of Berberis vulgaris × B. thunbergii hybrids to Puccinia graminis tritici and P. graminis secalis*

Crosses	Reaction of hybrids [1] to—			
	P. graminis tritici		P. graminis secalis	
	Resistant	Susceptible	Resistant	Susceptible
B. vulgaris × B. thunbergii F_1 (F_1 individuals)	[2] C. B. 1		[2] B. C. 1 B. C. 2 B. C. 3	C. B. 1
B. vulgaris × B. thunbergii F_2 (F_2 individuals)	[3] 207 (3, 9, 14)	[4] 207 (*x*)	[3] 201 (1, 2, 5, 9, 10, 11)	201 (6, 8)
				202 (1, 2, 3)
			[3] 204 (3, 9, 10, 11)	204 (2)
			[3] 205 (3, 6, 9)	[4] 207 (*x*, 2, 3, 5, 10, 14, 18, 19, 22, 27)
			[3] 206 (2)	
			[4] 207 (*x*, 9, 11, 15, 23, 28, 29, 30)	
B. C. 1 × B. vulgaris (back cross)		203 (2)	203 (2)	203 (1, 2)

[1] Individuals are grouped according to F_2 families and back crosses. For example, 201 (1, 2, 5, 9, 10, 11) means individuals 1, 2, 5, 9, 10, and 11 of family 201.

[2] According to Blakeslee, B. C. 1, 2, and 3 and C. B. 1 are F_1's from crosses made in 1914 between *Berberis thunbergii* and the purple-leaved variety of barberry.

[3] Numbers given by A. H. Blakeslee, Carnegie Institute for Experimental Evolution, Cold Spring Harbor, N. Y.

[4] *x*=plants plowed up in the nursery and replaced without numbers.

The plants used in this study were furnished by A. H. Blakeslee, of the Carnegie Institute for Experimental Evolution at Cold Spring Harbor, N. Y. They were crosses between *Berberis vulgaris atropurpurea* and *B. thunbergii*. The plants were removed from the field at that place and shipped to St. Paul, Minn., where they were potted and subsequently inoculated on the appearance of new leaves. They were inoculated with *Puccinia graminis tritici* form 18 from Laramie, Wyo.; *P. graminis secalis* form 9 from Wanamingo, Minn.; and *P. graminis secalis* form 11 from Litchfield, Minn.

The purple-leaf common barberry parent was determined as susceptible. The other parent, *Berberis thunbergii*, is known to be immune. Of the four F_1 individuals referred to in footnote 2 of Table 3, one, C. B. 1, was susceptible, while three, B. C. 1, B. C. 2, and B. C. 3, did not rust as a result of the five inoculations made. Of the three individuals obtained from a back cross of B. C. 1 × Purple, two were susceptible and the third was rust free in three inoculations. Of these inoculations, only the series in which the checks were infected are included.

Of the four individuals obtained from a cross of B. C. 1 × B. C. 3, three of the four F_2 individuals are susceptible, the status of the other being unknown.

Data are available on the reaction of 38 F_2 individuals belonging to six F_2 families of a population of 45. Of this number, 22 were immune from and 16 susceptible to *Puccinia graminis secalis* in repeated inoculations. These small numbers constitute a ratio of three to two and are not definitely indicative of the number of genetic factors involved. Nor is it possible to ascertain from the reaction of either the F_1 or F_2 generation whether resistance or susceptibility is dominant.

In this particular cross, susceptible plants were in general like the susceptible parent in morphologic characters. The leaf color of most of the plants was green, very few purple-leaf plants being present. All the purple-leaf plants were susceptible. The immune individuals resembled the *Berberis thunbergii* more than the *B. vulgaris* parent; therefore, it would seem that there is a correlation between morphologic characters and resistance to *Puccinia graminis*. This makes the eradication of barberries easier, as apparently there is but little ground for the fear that there may be numerous hybrids that look like *B. thunbergii* but rust like *B. vulgaris*.

GERMINATION OF TELIOSPORES

The species and varieties of Berberis susceptible and those resistant to rust having been determined, experiments were made to ascertain the conditions governing infection of the susceptible varieties. *B. vulgaris* was the principal species used in the experiments. Obviously, the first factor to be considered in studying the sequence of infection in the aecial stage is the germination of the teliospores.

It has been known for many years that the germination of teliospores is capricious. De Bary (*2, p. 24*) observed that they rarely germinated immediately after their formation. It is definitely known that a resting period is required before they can germinate. Just what is the nature of the change that occurs between the time of formation of the teliospores and that of their physiologic maturity is not known. Numerous attempts have been made to determine the factors affecting maturation and germination, but the problem is still very imperfectly understood.

McAlpine (*11*), Klebahn (*9*), Thiel and Weiss (*18*), and Lambert (*10*) made experiments to determine whether temperature affected the maturation of the spores, but all concluded that this factor alone exerted only a minor influence. Likewise, Klebahn (*9*) and Lambert (*10*) concluded that moisture alone had very little influence on the maturation of teliospores. Lambert (*10*) also found that light had very little effect. Waters (*20*) has shown that the formation of telia may be hastened by placing plants infected with *Uromyces appendiculatus, Puccinia sorghi, P. suaveolens, U. trifolii,* or *U. polygoni* in the dark. In general, it may be said that the teliospores formed in the fall usually do not germinate until the following spring or the season corresponding to it.

Numerous attempts have been made to break the period of dormancy of the spores, but most of them have failed. Thiel and Weiss (*18*) found in the winter of 1920–21 that teliospores treated with citric acid germinated readily, while nontreated spores from the same lot did not germinate. Similar attempts since that time, however, have been unsuccessful. Lambert (*10*) tried to stimulate germination by using several chemicals, but found none effective.

After the maturation of the teliospores, germination may be influenced by moisture and temperature and probably less by light and hydrogen-ion concentration. Melhus et al. (*13*) found that "at a humidity of 95.6 per cent, only a slight production of sporidia was obtained," and "the most prolific sporidia formation occurred in a saturated atmosphere."

Dietel (*5*) thought the minimum temperature for the germination of *Puccinia graminis* teliospores to be 9.5° C., the maximum 23°, and the optimum 22°. Melhus et al. (*13, p. 290*) state: "* * * sporidia formation may occur only between 5° and 25° C. and seems most profuse at 20° C. * * *" Lambert (*10, p. 11*) states: "* * * the spores germinated well at 12° to 18° C. but they germinated most consistently at 18° C."

Lambert (*10, p. 11–12*) found "no consistent differences" between germination of spores in diffuse sunlight and in darkness. He further states that "some collections of teliospores will germinate in a fairly wide range of H-ion concentration," and that "different collections of teliospores differ considerably with regard to the time required for germination."

When teliospores of the *tritici* and *secalis* varieties were used to inoculate barberries for 2 days, then dried for periods of 1 to 10 days before being used to inoculate other barberries, the infection produced by both varieties was practically the same in both trials.

With regard to the longevity of mature teliospores, Lambert (*10, p. 13*) says: "It has been observed repeatedly that under natural conditions they usually are comparatively short-lived." Regarding the best method of storing telia to retain their viability, he (*10, p. 13, 15*) states: "It will be noted that material kept dry and at the lowest temperatures remained viable for the longest time." He mentions that telial material of *Agropyron repens* was placed in storage at approximately 2° C. and that "Cotter continued his inoculations with the spores * * * and was able to obtain infection until spring." This material was left in cold storage during the summer.

On August 31, 1926, *Berberis lycium, B. pruinosa, B. vulgaris,* and *B.* (*Mahonia*) *repens* were inoculated with the material mentioned.

A very light infection occurred on *B. vulgaris*. Another series, inoculated the same day with the same material, consisted of *B. aggregata prattii*, *B. brachypoda*, *B. leichlinii*, and *B. vulgaris* used as a check. On *B. leichlinii* a moderate infection of pycnia appeared September 13, and aecia were noted on September 27. A very light infection, apparently monosporidial, appeared on *B. vulgaris* September 14. No aecia appeared. From these data it seems that telia may retain their viability for a year and a half when kept in a dry place at a temperature slightly above the freezing point. These telia were formed in the fall of 1924 and produced some infection the latter part of August, 1926.

In the spring of 1926 teliospores on *Agropyron repens* (L.) Beauv. were collected near Red Wing, Goodhue County, Minn. These telia were used in the inoculations made in 1926 and 1927. The last inoculations with this material were made in May, 1927. On May 12 *Berberis arvensis*, *B. heteropoda*, *B. lycium*, and *B. notabilis* were inoculated with teliospores from this source. A moderate pycnial infection appeared on *B. arvensis* May 21, and aecia appeared on June 6. A light pycnial infection appeared on *B. lycium* May 20, no aecia being observed. A moderate infection of pycnia appeared on *B. notabilis* May 20 and aecia appeared on June 1. On May 16 *B. alesuthensis*, *B. aristata*, *B. haematocarpa*, *B. swaseyi*, and *B. vulgaris* were inoculated with this same material. Light infection occurred on *B. alesuthensis* and *B. haematocarpa* and moderate infection on *B. swaseyi* and *B. vulgaris*. Aecia developed on *B. vulgaris* 12 days later. Inasmuch as these teliospores were formed in the fall of 1925 and caused infection in the spring of 1927, it appears that spores of this collection were still germinating well a year and a half after the formation of the spores and a year after having been placed in the cold-storage room. In this connection, Eriksson (*6*) showed in 1898 that teliospores from wheat stored for two years in a dry laboratory germinated after having been kept in the open during the winter.

In the upper Mississippi Valley teliospores under outdoor conditions usually begin to germinate in April or May, and the question arises how long they will remain viable under such conditions. Under outdoor conditions, Melhus et al. (*13*) obtained plentiful germination in April and May, but spores left out of doors would not germinate in June or July. Lambert (*10*) found similar conditions at St. Paul in 1923 and 1924. The teliospores from a collection of telia on wheat collected at Black Earth, Wis., and placed out of doors at St. Paul by the writer germinated well on February 23, 1926. The teliospores from this collection did not germinate March 9, 1926, or later. Teliospores on *Agropyron repens*, left out of doors at St. Paul in the winter of 1926, germinated fairly well in March but very indifferently two weeks later. The teliospores from *A. repens* left out of doors at St. Paul in the fall of 1928 germinated weakly on March 26, 1929, but not at all on April 10. As snow or rain had fallen after the first inoculation in each of the cases cited, the teliospores probably had germinated before the second inoculation was made. In these cases the teliospores had been germinating before and after the first inoculation; so when the second inoculation was made, all of the teliospores had germinated. Teliospores left out of doors during the winter at St. Paul germinated before the middle of April in 1926, 1927, and 1928.

Infection may not occur even though the teliospores have germinated and the sporidia have lodged upon the barberry leaf. In nature the conditions at the time the barberry leaves are unfolding are extremely variable. Rains may be intermittent, so that the film of moisture necessary to the life of the sporidium may disappear before the germ tubes can penetrate the leaf; the temperature may drop so low that growth of the germ tubes is very slow, while the cuticle and epidermis of the leaf is thickening to such an extent that the germ tube can not penetrate it; or the teliospores may germinate before the barberry leaves appear. A study of the conditions under which infection of barberry leaves may occur is desirable to clear up the present state of uncertainty as to the influence of moisture, temperature, light, age of leaves, and the necessary incubation period on the infection of barberries. To this end several experiments were made.

RELATION OF AGE AND FREEZING OF TELIOSPORES TO INFECTION OF BARBERRIES

The writer observed that from teliospores collected in the spring of 1925, 1926, 1927, and 1928 a much heavier infection of barberries resulted than was obtained from spores of the same collection a year later. On three occasions telia were tested a year and a half after collection, and the germination and resultant infection were very weak, even when the spores had been kept in a cold, dry place. If teliospores are not kept at a low temperature (about 0° C.) and dry, they lose their viability rapidly. Occasionally they lost all power to produce sporidia within two weeks from the time germination was first noticed in the collection.

Freezing viable telia of the *tritici* and *secalis* varieties at a temperature of −5° C. for two days did not appreciably lower the germination of the teliospores below that of the check, as determined by the amount of infection produced on barberries.

RELATION OF TEMPERATURE TO INFECTION OF BARBERRIES

As temperature fluctuations at the time of the appearance of the first barberry leaves usually are very great, it is of the highest importance to determine the effect of temperature on the infection of barberries. Experiments therefore were made to determine the importance of this factor.

Lambert (*10, p. 19*) found that "the greatest amount of infection occurred at 17° to 18° C." He states:

> This experiment indicates that the combined process of teliospore germination, sporidia formation, liberation, and germination, the infection of barberry leaves, and the development of aecial cups are retarded or prevented by temperatures higher than 22° C.

To test this point, the writer repeated the experiment, using slightly different temperatures. The teliospores used as inoculum were scraped from the straw and placed upon the surface of distilled water in Syracuse dishes, which were then placed at temperatures of 10°, 14°, 21°, and 26° C., one dish of teliospores from wheat and one from *Agropyron repens* being placed at each temperature. At the end of two days many spores presumably had germinated and produced sporidia, for infection was readily secured with spores so treated in previous experiments. Only susceptible varieties of Berberis, principally *B. vulgaris*, were used, except as otherwise noted. Before inoculation the barberry leaf was wetted and the bloom removed,

after which a drop of the telial suspension was placed on the young leaf by means of a loop needle inserted below the surface of the liquid and then lifted so as to carry with it the teliospores and their sporidia almost undisturbed. After the plants had been thoroughly wetted with water, they were placed in containers in a temperature tank for two days. The plants were sprayed with water at intervals of about three hours during the day for two days in order to maintain the film of moisture around the spores. At the lower temperatures it was not difficult to maintain this film of moisture, but at 24° to 26° C. and 31° to 35° it was more difficult. Notes were taken on the first appearance of infection, as shown by the appearance of pycnia, on the first appearance of aecia, and on the degree of infection. The results are given in Table 4.

TABLE 4.—*Effect of temperature on rate and degree of development of rust infection on Berberis vulgaris inoculated with teliospores of Puccinia graminis tritici and P. graminis secalis and incubated in a continuously saturated atmosphere*

Telial host	Temperature for spore germination	Number of days required for appearance of pycnia and aecia and degree of infection[1] produced at temperatures of—											
		8°–10° C.		12°–14° C.		16°–18° C.		19°–21° C.		24°–26° C.		31°–35° C.	
		Pycnia	Aecia	Pycnia	Aecia	Pycnia	Aecia	Pycnia	Aecia	Pycnia	Aecia	Pycnia	Aecia
	°C.												
Agropyron repens	9–10	9+−	23+−	------	------	8+−	21+−	6++	21++	9+	23+	------	------
	12–14	------	------	8+	25+	------	------	8++	7++	14+−	0	8+−	0
	19–21	21+−−	0	------	------	9+−	21+−	9+	25+	21+−−	27+−−	------	------
	24–26	21++	27++	12+−	28+−	21+−−	0	9+	29+	8+	25+	------	------
Wheat	12–14	------	------	------	------	------	------	8++	7++	------	------	------	------
	24–26	------	------	8++	24++	------	------	8+−	0	8+	28+	------	------

[1] The degree of infection is indicated by the following symbols: ++, Heavy; +, moderate; +−, light; +−−, very light; 0, none; ------, no trial.

It will be seen from Table 4 that only one very light infection resulted at 31° to 35° C.; hence it may be concluded that the combined process of teliospore germination, formation, liberation, and germination of sporidia, and barberry infection was greatly inhibited, if not prevented, by temperatures higher than 26° C. The optimum temperature seems to be 19° to 21°. Lambert (*10*) thinks the optimum for barberry infection is 17° to 18° and that infection does not take place readily above 22°, while Melhus et al. (*13*) state that the maximum for formation of sporidia is 25° and that a saturated atmosphere is necessary. This, however, is difficult to maintain at temperatures of 24° to 26° and 31° to 35°.

After inoculation the barberries listed in Table 4 were held two days at the same temperature at which the teliospores germinated. Then four of the five plants in each series were changed to the incubating temperatures, where they remained until notes were taken on all the plants. However, in this experiment one factor has not been eliminated, namely, the possibility that the teliospores incubated at the germinating temperature might not have germinated at that temperature, but might have germinated when the inoculated plant was transferred to the incubating temperature. To remedy this defect further inoculations of *Berberis vulgaris* were made.

Teliospores from *Agropyron repens* from Rochester, Minn., were placed in distilled water and incubated two days at each of five temperatures. Five plants of *Berberis vulgaris* were inoculated with the spores incubated at each temperature, and these plants were held at the same temperature for two days, during which they were sprayed with water from an atomizer every three hours during the day. At the expiration of this period four of the five pots held at each temperature were shifted, one to each of the other four temperatures, where they were left until the notes had all been taken. When shifting the four pots the plants were thoroughly dried before being placed at the different temperatures. This procedure obviates the possibility of infection occurring at a temperature other than the original spore-germination temperature. The results of the inoculations are given in Table 5.

TABLE 5.—*Influence of temperature on the rate and degree of development of pycnial infection on Berberis vulgaris inoculated with teliospores of Puccinia graminis secalis and incubated two days in a saturated atmosphere, dried, and replaced in the chambers*

Temperature (° C.) for spore germination	Number of days required for appearance of pycnia and degree of infection[1] produced at temperatures (°C.) of—				
	7°–9° C.	15°–18° C.	19°–21° C.	24°–26° C.	31°–35° C.
7–8	15+−−	11+−−	8++	------	8+
8–9	10+−−	7++	5+	6++	7+−−
15–16	0	0	7+	7+−−	6+
16–18	8+++	6+	4++	0	0
19–20	8+−	4++	4++	4++	0
20–21	13+	7+	7+	8++	0
24–26	11+	0	0	11+−	0
31–33	0	0	0	0	0
33–35	0	0	0	0	0

[1] +++, Very heavy; ++, heavy; +, moderate; +−, light; +−−, very light; 0, none; ------, no trial.

The results given in Table 5 are a little more clear-cut than those in Table 4. The data indicate that the processes of germination of teliospores, formation, liberation, and germination of sporidia, and penetration of barberries do not take place freely at temperatures of 24° to 26° C. and 31° to 35°, as no infection was secured from the teliospores incubated at these two temperatures. The smallest amount of infection resulted from the teliospores incubated at 7° to 9°, while moderate infection developed at the three lower temperatures, from the telia germinated at 15° to 18° and 19° to 21°. It is noteworthy that infection appears first at the higher temperatures and last at 7° to 9°, the optimum temperature being 19° to 21°.

The evidence presented seems to show that teliospores of *Puccinia graminis* rarely if ever germinate and produce and liberate sporidia at temperatures higher than 26° C. This is in accordance with the results of Melhus et al. (*13*), who found 25° the maximum for production of sporidia, and Lambert (*10*), who found that there was light infection at 22° to 23° and little or none at 26°.

INFLUENCE OF LIGHT ON INFECTION OF BARBERRIES

Next to temperature and moisture, light is perhaps one of the most important factors in the development of rusts. Therefore, the effect

of light and darkness on infection of barberries was also investigated.

Lambert *(10, p. 22)* found that—

> Different amounts of light during the period of incubation apparently had no effect on the percentage of leaves infected, but the number of infected petioles was markedly greater on the plants kept in total darkness than on those exposed to constant intense light.

Heavily rusted straw was supported on wire screens above *Berberis vulgaris* and wetted twice daily. By this method heavy infection usually is secured. After removal from the incubators, one of the plants was kept in constant light under a 500-watt light suspended 4 feet above the table, one was placed on the greenhouse bench where it was exposed to alternate light and darkness, and the third was kept in a dark room at a temperature of about 10° C. until sufficient time for the appearance of pycnia had elapsed. The results are given in Table 6.

TABLE 6.—*Influence of light on production of pycnia on Berberis vulgaris inoculated with teliospores of Puccinia graminis secalis in the greenhouse*

Date of inoculation	Number of days required for appearance of pycnia and aecia under indicated light conditions after removal from moist chambers, and degree of infection[1] produced					
	Alternate light and darkness (diurnal)		Constant light		Constant darkness	
	Pycnia	Aecia	Pycnia	Aecia	Pycnia	Aecia
Jan. 12	8 ++	18 ++	10 +−−	+−−	0	0
	11 ++	++	8 ++	18 ++	11 +++	+++
Jan. 19	9 +	+	0	0	0	0
	8 +	23 +	9 +	+	14 +	+

[1] +++, Very heavy; ++, heavy; +, moderate; +−, light; +−−, very light; 0, none.

No conclusions can be drawn from the data in Table 6, because the plants kept in total darkness were held at a temperature of 10° C., while the plants in constant light and alternate light and darkness were kept at a temperature of 20°, so the results are not comparable. While the cold temperature would tend to retard the appearance of infection whether in total darkness or in constant light, the fact that infection did appear as soon on the plants inoculated January 12 and kept in total darkness as on the plants subjected to alternate light and darkness would tend to discredit the idea that light alone has any decided effect on the occurrence of pycnial infection. Later experiments carried out at a temperature of 10° indicated that the infection becomes apparent slightly earlier on plants kept in constant light during the processes of inoculation and incubation than on those inoculated and incubated in chambers kept constantly dark.

TIME REQUIRED FOR INFECTION OF BERBERIS VULGARIS WITH TELIOSPORES OF PUCCINIA GRAMINIS SECALIS

As far as the writer knows, no one actually has determined the time necessary for infection of barberries from the time the telia are first wetted until infection occurs.

The question is important because of the fact that in nature the teliospores germinate on straw, where they produce sporidia which

must be blown to barberry plants, where they germinate and produce germ tubes that penetrate the host. Environmental factors therefore must be favorable for a longer time to insure infection of barberries than in the case of infection of gramineous hosts with aeciospores and urediniospores. Just how long conditions must be favorable is not known.

To solve this problem, a suspension of teliospores in water was prepared and used immediately to inoculate *Berberis vulgaris* plants, which were at once placed in moist chambers where they were kept moist for the duration of the experiment.

No infection resulted when *Berberis vulgaris* plants inoculated with teliospore suspension from *Agropyron repens* were incubated for 17, 18, 24, 30, and 42 hours, respectively, in various series at greenhouse temperature. Other plants in these series became infected when incubated for 41, 48, 50, 66, 90, 113, and 119 hours, respectively, at greenhouse temperature. Development of pycnia was very light on the plants incubated 41 hours; the infection on the plants incubated 50 hours was only slightly heavier; and the infection resulting from longer incubation periods was moderate to heavy. The results indicate that a period of at least 66 hours was necessary for the germination of the teliospores, formation of the promycelia, production, liberation, and germination of the sporidia, and subsequent infection. The severity of infection was but little greater when the incubation period was 72 hours or longer. This, then, means that barberries probably become heavily infected in nature only when favorable weather conditions prevail more or less continuously for two or three days.

To determine the minimum length of time necessary for susceptible barberries to become infected under the most favorable conditions, teliospores from *Agropyron repens* collected near Rochester, Minn., were soaked two days in water and used as inoculum. The incubation chamber was a tall metal can covered by a pane of glass and with about an inch of water in the bottom to supply the necessary humidity. The potted barberry plants were placed in the chamber, wooden sticks were inserted into the soil in the pots, and a coarse ½-inch mesh wire screen was placed on top of the wooden sticks. The telial material was placed upon this wire screen so that the sporidia fell in a shower over the plants below. Twice a day this material was wetted with water. Four barberry plants were designated as a series in each chamber, and certain plants of each series were removed at definite times. Plants exposed to the sporidial shower 1½, 2, 3, 8, and 24 hours did not become infected; but plants in the same series exposed 21, 29, 33, 45, 46, 47, 48, 55, 69, and 71 hours became infected. The infections were light on the plants exposed 21 and 29 hours, moderate on those exposed 33 hours, and heavy on those exposed 45 hours. It was to be expected that plants exposed for longer periods to the sporidial shower would be heavily infected, and such was the case.

In these experiments the minimum time required for liberation and germination of sporidia and barberry infection was 21 hours. However, the limited available data and the wide gaps in time of exposure in the various groups made further information desirable. This experiment also raised the question as to how long the telial material would have continued active in supplying inoculum if the

experiment had been continued. Another point deemed worthy of investigation was the length of time that must elapse before the teliospores kept in a moist atmosphere discharge the maximum number of sporidia.

Telia on quack grass from Rochester, Minn., were soaked in tap water two days prior to being used as a source of inoculum. Five pots of *Berberis vulgaris* were exposed to the sporidial shower from this material. One pot was removed after exposure for 28 hours, and developed a light infection; the other four were exposed 45 hours and developed light to moderate pycnial infections.

Four plants of *Berberis vulgaris* were exposed to the telia used in the foregoing series. One plant, subjected 6 hours, did not become infected, while a second plant, exposed 24½ hours, became heavily infected. The other two plants, exposed 27 hours, also became heavily infected.

The same rusted straw was used again as a source of inoculum for a third series of *Berberis vulgaris*. All four of the plants were exposed to the sporidial shower 45 hours and eventually developed a moderate to heavy pycnial infection. The results show that sporidia were being liberated 116 hours from the time straw was first wetted and 50 hours from the time the first infected barberry was removed from the incubation chamber.

As a check on the foregoing series, and in order to determine whether collections of telia on *Agropyron repens* would cause similar reaction, telia from Hennepin County, Minn., were similarly soaked for two days before they were employed as a source of inoculum.

As in the first series of the previous experiment, one of the plants was exposed to the supposed sporidial shower 28 hours and the other three were exposed 45 hours, but no infection resulted. The results show that each teliospore collection is a law unto itself. These two collections were gathered about the same time from localities similar in climate and not very widely separated. Barberry infections were obtained from the Rochester collection 96 hours after the telia had been soaked in water; from the Hennepin collection barberry infection developed after the rusted straw had been soaked 117 hours. The known time of spore discharge of the Hennepin teliospores is 46 hours and of the Rochester material 88 hours. The Rochester material germinated first and over the longer period of time. The telial material was used again for a supply of inoculum, and some infection resulted. A plant exposed 6 hours did not show any signs of infection, but plants exposed 24 hours became lightly infected, as did two plants exposed 27 hours. In the third series with this telial material, four *Berberis vulgaris* plants, exposed 44 hours to the sporidial shower, became lightly or moderately infected.

It is evident that for some reason germination of the teliospores in the Hennepin collection did not occur so readily as in the Rochester collection, although both collections were gathered within a few days of each other from localities 80 miles apart. The first infection recorded from the use of the Hennepin material was on a plant exposed 24 hours in the second series and 117 hours after the material was first wetted. The first recorded infection from the use of the Rochester material was on a plant exposed to the shower of sporidia for 28 hours after the telia had been soaked in water 48 hours. The known time of spore discharge by the Hennepin teliospores covered

a period of at least 46 hours, as shown by the infections that occurred on the barberries exposed to the sporidial shower during that time. The known time within which the Rochester teliospores produced sporidia is 88 hours, as judged by the infections produced on barberries removed from the incubation chamber during that time.

In a third experiment rusted quack grass from an unknown source was similarly soaked for two days before being used to inoculate barberries. The material was divided into two parts, the second series of barberry plants being inoculated six hours later than the first, with telia soaked six hours longer.

In the first series, plants exposed 5½ and 8½ hours did not become infected, while plants exposed 26 and 33 hours became heavily infected. In the second series, infection occurred on all the plants, even though they had been exposed to the sporidial shower only 7, 23, 26, and 30 hours, respectively, the infection ranging from light on the plant exposed 7 hours to very heavy on the plant exposed 30 hours.

In the second half of the experiment three plants exposed 1, 2, and 3 hours, respectively, did not become infected. The fourth plant, exposed 20 hours, became heavily infected. Plants of the second series exposed to this telial material were all heavily infected after 15, 18, 24, and 39 hours.

The teliospores from the two series were combined to furnish inoculum for a series of plants of *Berberis vulgaris*. Infection occurred on all members of the series after exposures of 5, 12, 24, and 49 hours.

A third series exposed to this combined telial material became infected after an exposure of 48 hours. Two plants of *Berberis vulgaris* were subsequently inoculated with this material. One light infection was noted on one of the two plants after an exposure of 23 hours. When two plants of *B. vulgaris* and one of *B. canadensis* were inoculated with the same material after the removal of the previously inoculated plants, light infection occurred on the *B. canadensis* plant and on one of the *B. vulgaris* plants after an exposure of 25 hours. This telial material had first been immersed in tap water at noon February 9. The first infection obtained was on a plant exposed to a shower of sporidia for 26 hours and removed 72 hours from the time the teliospores were first wetted. The last infection obtained was on two plants removed from the incubation chamber after exposure to a sporidial shower for 25 hours produced by telial material wetted in tap water for 264 hours, or 11 days.

From these results it appears that barberry plants may be infected by telial material that has been continuously wet for 11 days. Such a continuous discharge of sporidia means that under natural conditions, during long periods of rain, the barberries in the vicinity of heavily rusted grains or grasses are exposed to a constant shower of sporidia, so that infection is almost certain to occur on the barberry plants. If there are periods of alternate rainfall and dry, warm weather successive infections on barberry may result. If barberry leaves are not unfolded when the first teliospores germinate, little or no infection occurs; but as the successive periods of germination of teliospores occur, some and possibly all of the barberry leaves are very likely to become infected.

To complete the data, another double series of plants was exposed to teliospores from quack grass from an unknown source. To gain some idea of the time when the first sporidia were formed, half of the telial material was used as inoculum two hours after it had been placed in tap water, the other half being used three days later, because in one of the preceding experiments it seemed that the teliospores did not germinate in the tap water in which they were soaked but did germinate shortly after being placed on the screens above the plants, where they had access to plenty of oxygen and moisture.

In the first series, in which the telia had been presoaked two hours before being used as inoculum, *Berberis vulgaris* plants exposed to possible infection by sporidia for periods of 21 and 29 hours, respectively, became lightly infected, while those exposed for 45 and 70 hours, respectively, became heavily infected. In a series inoculated with the other half of this material, three *B. vulgaris* plants exposed for 1, 2, and 3 hours, respectively, did not become infected, whereas the fourth plant, exposed 47 hours, became heavily infected. In a third series, exposed to telia from the first series, plants exposed 9 and 24 hours did not become infected. The other plants, exposed 33 and 48 hours, respectively, became moderately infected.

From the foregoing it is evident that the 2-day presoaking was not necessary for the germination of the teliospores. The first plant removed from the incubation series, 21 hours after inoculation and 23 hours after the water was put on the telia, was infected. While the degree of infection was light, further experimentation might have revealed that infection may take place in a still shorter time. From the facts here given, however, one can say that the processes of germination of teliospores, and formation, liberation, and germination of sporidia, with subsequent penetration of the barberry leaf, can, under favorable conditions, take place in a minimum time of 23 hours.

The other half of this telial material, presoaked three days before using, failed to produce infection on a *Berberis vulgaris* plant exposed to it 3 hours, but did produce infection on plants exposed 46, 55, and 71 hours, respectively. The degree of infection was, however, very light. In a second series inoculated with this telial material, no infection was secured after exposures of 3, 5, and 23 hours. Thus, it appears that presoaking the telia for two days promotes germination, and but little infection usually results if the material is kept moist longer than two days. The writer believes that soaking the telial material for two to six hours before using it for inoculation will provide for the least loss of sporidia with the maximum number of germinated teliospores. Furthermore, short periods of rain, followed by conditions unfavorable for dissemination of sporidia and infection of barberry plants, would result in considerable loss of potential infective power, as far as the pathogene is concerned. It will be recalled that in the previous experiment the teliospores germinated over a period of 11 days when suspended on a wire screen in a moist chamber. In this experiment it appears that nearly all the teliospores germinated in three days when taken from the same collection, kept under the same conditions, and soaked three days in tap water.

Under natural conditions most of the teliospores from low places, such as swamps, may germinate at about the same time, while those on grains or grasses in higher, well-aerated places may germinate at different times.

SUSCEPTIBILITY OF BARBERRY LEAVES OF VARIOUS AGES AND SPECIES

It is known that the age of barberry leaves at the time of inoculation is a factor in infection with *Puccinia graminis*. Melhus et al. (*13*) state:

> Repeated attempts in the greenhouse and field under varied moisture and temperature conditions failed to produce infection on the more mature leaves * * *. The marked difference in the susceptibility of young and old leaves of the barberry may be due to the thickness of cuticle and epidermis, considering that infection is accomplished by penetration of the tissues and not through invasion of stomata.

Melander and Craigie (*12*) think that the leaves of susceptible species become virtually immune with age.

The leaves of the barberry plant can unfold and grow under conditions that do not permit infection. If, then, only the very young leaves are susceptible, many of them would escape infection if weather conditions were not favorable during the period of their immaturity. If, on the other hand, the leaves remain susceptible for a considerable period, the chances of infection would be much greater.

To obtain evidence on this point, rapidly growing plants of *Berberis vulgaris* were examined daily for 11 days, and to each new leaf a tag was attached bearing the date the leaf unfolded. On the eleventh day, eight of these barberry plants were inoculated with sporidia of *Puccinia graminis secalis*. Pycnia appeared five days later. Notes were taken on the number of leaves infected on the several dates, the age of the leaves, and the degree of infection produced on each leaf each day. Some of the results are given in Table 7.

TABLE 7.—*Influence of age of barberry leaves on development of rust in the greenhouse*

Age of leaves (days)	Berberis vulgaris											Berberis aetnensis					
	Number of leaves inoculated	Number of leaves infected at indicated number of days after inoculation					Number of leaves inoculated	Number of leaves infected at indicated number of days after inoculation				Number of leaves inoculated	Number of leaves infected at indicated number of days after inoculation				
		7	8	9	10	15		5	8	10	12		7	8	9	10	15
1	3		2	3	3	3	7	1	6	6	7	2	2	2	2	2	2
2	4	4	4	4	4	4	3	1	3	3	3	5	5	5	5	5	5
3	17	8	9	13	14	17											
4	6	2	2	3	6	6	1	1	1	1	1	11	5	6	8	10	11
5	2		1	1	1	1	1		1	1	1						
6	6	1	3	4	4	6	5		2	5	5						
7	13	5	6	13	13	13	1		1	1	1	2	1	1	2	2	2
8	3	1	1	2	2	3	4			3	4	8	1	6	6	7	8
9	9		1	2	2	3						3	2	2	3	3	3
10	14	1	3	8	10	12						9	1	2	5	8	9
11	9		2	5	6	9	2				2	1			1	1	1
12	14			8	10	14	4		2	4	4	9		4	5	7	9
13							4			2	2						
14							7			2	2						
15							7			2	3						
16							5				1						
Total	100	22	34	66	75	91	51	3	16	30	36	50	17	28	37	45	50

The data given in Table 7 show that infection appears first on the younger leaves and two or three days later on the older leaves. This probably is due to the difficulty the fungus experiences in puncturing

the cuticle of the older leaves and perhaps in penetrating the tissues of the older leaves before ramifying inside the tissues. Since heavy infection was noted on leaves 14 and 15 days old, apparently the age of the leaf is not a factor in determining the resistance or susceptibility of any given species, provided the fungus is able to penetrate the leaf, the infection being just as heavy on leaves inoculated when 15 days old as on those inoculated when 1 day old.

It is evident from Table 7 that leaves of *Berberis vulgaris* may be infected by *Puccinia graminis* as late as 16 days after they first appear. As many of the tags showing the age of the leaves were dislodged during the inoculations, the ages given in Table 7 are not so great as they otherwise might have been; but since leaves that apparently were at least 2 days older than the tagged 16-day leaves were moderately or heavily infected, it is thought that if none of the tags had been dislodged leaves still older than 16 days might have proved susceptible.

Undoubtedly, insolation exerts some indirect influence on the ease with which the fungus can penetrate barberry leaves. In the experiments, the results of which are given in Table 7, 9 of the 17 days during which barberry leaves were being tagged were cloudy, while the sun shone brightly on 8 days. The forenoons of 2 days were cloudy and the afternoons were sunny. These days were included in the totals as 1 cloudy and 1 sunny day. Had all the days covered in this experiment been sunny, it is quite possible that infection would not have occurred on common barberry leaves 16 days old, as Melander and Craigie (*12*) found that leaves of *Berberis vulgaris* 10 days old were somewhat resistant. There was no correlation between the degree of infection and the presence or absence of sunshine on the day the leaves appeared, as leaves of the same date showed the extremes of infection, from very light to very heavy.

From Table 7 it is clear that the total numbers of leaves of *Berberis vulgaris* inoculated and infected are the same, with one exception, up to and including the eighth day, whereas in *B. aetnensis* the total number of leaves inoculated and infected correspond up to and including the twelfth day. With *B. vulgaris* it was possible for every tagged leaf to become infected up to the twelfth day. All the 12-day leaves tagged on that day became infected, but not all the 9-day and 10-day leaves were infected. Infection became more uncertain, however, on leaves 13 to 16 days old, and on the sixteenth day only one of the five inoculated leaves became infected, and then but very lightly. In the case of *B. vulgaris* there seems to be a gradual hardening off of the leaves after the eighth day, although there is no evidence that this occurs in leaves of *B. aetnensis*. The results support the conclusions of Melander and Craigie (*12, p. 99*), who state: "Leaves of *B. vulgaris* 10 days old are fairly resistant to *P. graminis*. This would indicate a close correlation between resistance and the thickness of the outer epidermal wall." But the results also show that leaves remain at least moderately susceptible for 10 days to two weeks, especially if weather conditions are such as to prevent them from hardening. This fact, of course, is favorable for the pathogene during the spring.

Observations were made to determine those parts of the common barberry that are most susceptible to infection by *Puccinia graminis*. Data were gathered on a number of infected plants. The degree of

Leaves of *Berberis ilicifolia* infected with *Puccinia graminis secalis*. Note the profuse growth of aecia on the petioles, resulting in the death of the leaves

Berberis vulgaris infected by *Puccinia graminis secalis*

infection was noted on the leaves, stems, petioles, spines, leaf spines, and growing points of the stems. Field observations were made on infection of the flowers of *Berberis vulgaris*. The greenhouse data are given in Table 8.

TABLE 8.—*Susceptibility, in the greenhouse, of various plant parts of Berberis to black stem rust* [1]

Infection courts	Number of replications according to degree of infection indicated					
	B. vulgaris normalis			B. vulgaris atropurpurea		
	Moderate	Heavy	Very heavy	Moderate	Heavy	Very heavy
Foliage:						
Petioles	3	6	7			2
Leaves	3	5	13		1	2
Serrates	10	1		3		
Stem:						
Sprigs	1	1	7			
Spines	2		4			
Apices	1	1	1			

[1] Extremely heavy infection was once noted also on the nodes of *B. vulgaris normalis*.

The data in Table 8 show that any young or tender tissue on any part of the plant aboveground may be infected. Infection is more readily noticeable on the leaves than on any other part of the plant because of the much greater surface exposed to infection in comparison with that on the other parts of the plant. If infection occurs, however, other parts of the plant are just as susceptible as the leaves. Even the flowers may be infected. Common barberry collected at Rochester and Albert Lea, Minn., in 1928, was heavily rusted on leaves and sepals, with light aecial infection on peduncles and petals. Apparently there was also an infection on one of the stamens in one of the flowers. When *Berberis gilgiana* was artificially inoculated when blooming, infection developed on one of the petals as well as on the leaves.

In the early spring, barberry plants are subjected to a wide range of weather conditions. The frequent spring rains are often accompanied by lower temperatures, and this combination is especially favorable for teliospore germination and barberry infection.

Berberis vulgaris is generally supposed to be the species of barberry most susceptible to the attack of *Puccinia graminis*. In the writer's experiments, however, other species have become more heavily rusted and have been injured to a greater degree than *B. vulgaris*. Two such are *B. ilicifolia* Forst. and a strain of *B. canadensis* Mill. found in one section of Illinois. Frequently the entire leaf area of this *B. canadensis* strain became infected, with subsequent chlorosis and death of the leaves. Leaves of *B. ilicifolia* were frequently killed outright when inoculated in the same series with *B. vulgaris*, while on the leaves of *B. vulgaris* the infected areas were not continuous nor did any leaves die as a result of the attack of the fungus. There was little or no infection on the petioles of *B. vulgaris*, but there were very numerous aecia on *B. ilicifolia* three weeks after inoculation. The type of infection on *B. ilicifolia* is shown in Plate 1, and an un-

usually heavy infection on stems of *B. vulgaris* is shown in Plate 2. In Plate 3 is shown an infected whorl of leaves of *B. vulgaris*. It is evident from Plates 2 and 3 that the leaves of *B. vulgaris* are not killed as are those of *B. ilicifolia*. Even leaves having the exceptionally heavy infection shown in Plate 4 may live for weeks.

Of those species tested, *Berberis asiatica* Roxb. seems to be one of the most resistant. Leaves of *B. asiatica* are illustrated in Plate 5. In this case very small pycnial infections appeared at the same time as those on *B. vulgaris* and within 10 days became dry and brown. No aecia formed, whereas on *B. vulgaris* abundant aecia appeared. (Pl. 2.) Apparently the leaves of *B. asiatica* toughen rapidly and prevent the rust from spreading in the tissues.

EFFECT OF LENGTH OF INCUBATION PERIOD ON INFECTION OF BARBERRIES

If warm days follow the penetration of the sporidial germ tubes, the appearance of pycnia is accelerated, according to the data resulting from artificial inoculations. In the greenhouse the incubation period of the rust in the barberry is much shorter at temperatures of 20° to 30° C. than at temperatures below 10°. At the higher temperatures, 24° to 26°, pycnia appeared 3 to 10 days after inoculation, depending on the amount of consequent infection. Pycnia appeared on the third day upon the plant with the most infections, and on the tenth day upon one of the plants with the least infection. It was found that the first infection appeared on the most heavily infected plants and the last infection appeared on the very lightly infected ones. This would indicate that the amount of inoculum determines to some extent the rapidity with which infection becomes evident, as a leaf infected by a large number of sporidia produced pycnia before other leaves on the same plant that were inoculated with a few sporidia. During the last five years the writer has found that the pycnia first appear on the fifth to the tenth day following inoculations when the plants are kept under ordinary conditions in the greenhouse. Light alone seems to have no influence on the length of the incubation period of the fungus.

Wetting the barberry leaves and removing the "bloom" from them do not favor their infection. In a few of the writer's experiments those plants that did not have the leaves wetted nor the "bloom" removed were those that became most heavily infected. If more series had been inoculated the results might have been exactly the opposite of those already obtained.

EFFECT OF TEMPERATURE AND MOISTURE ON DEVELOPMENT OF AECIA

Plants of *Berberis vulgaris* with a moderate to heavy development of pycnia on the leaves were placed in the temperature chambers and observations were made to determine the time required for aecia to appear and mature. The results are given in Table 9.

A whorl of leaves of *Berberis vulgaris* infected by *Puccinia graminis secalis*, showing the manner in which all the leaves in a whorl may be heavily infected. Part of an aecial cluster on the stem above. Note length of aecial cups. × 5

Individual leaf of *Berberis vulgaris* infected by *Puccinia secalis*. This leaf had practically no green areas between the individual infections. × 5

TABLE 9.—*Effect of temperature on development of aecia and opening of aecial cups on Berberis vulgaris on which pycnia had been produced after inoculation with Puccinia graminis tritici and P. graminis secalis in the greenhouse*

Experiment No.	Telial host	Number of days required for appearance of aecia and for opening of aecial cups at temperatures of—									
		7°–8° C.		15°–16° C.		20°–21° C.		25°–26° C.		31°–32° C.	
		Appearance	Opening	Appearance	Opening	Appearance	Opening	Appearance	Opening	Appearance	Opening
1	Agropyron repens (L.) Beauv.	14	15	12	14	10	11	10	10	10	10
2	do	14	17	9	10	9	10	9	9	9	9
3	do	11	(1)	12	14	10	(1)	9	10	9	9
4	do	16	16	15	15	16	17	14	16	7	(1)
5	do	13	15	-------	-------	10	11	8	(1)	9	(1)
6	Triticum vulgare Vill.[2]	-------	-------	14	14	10	11	10	(1)	10	10

[1] Cups not open at expiration of experiment.

[2] According to the rules of botanical nomenclature the name of this species is *T. aestivum* L., but as *T. vulgare* is in general use among agronomists and cereal pathologists and geneticists, the writer gives preference to that form.

The data show that temperature has a marked effect on the appearance of aecia after pycnia have developed. At 25° to 26° C. aecia developed at the same time as at 31° to 32° except in those series where the amount of infection on the plants was not the same. The lowest temperature (7° to 8°) had the most retarding effect on the development of aecia. Temperature alone had no influence on the number of aecia, for as many developed at 7° to 8° as at 31° to 32°. There was, however, a very noticeable difference in the length of the aecial cups. At the lowest temperature the aecial cups were two to three times as long as at the highest temperature. At the temperature of 31° to 32° the aecial cups opened very soon after their formation and before they had become much elongated. They were rarely 1 mm long. The aecial cups formed at 7° to 8° were 2 to 3 mm long before they opened.

From an empirical experiment it appears that the influence of moisture on the formation of aecia is irregular, because in two trials aecia formed on the plants in the wet chamber after the formation of aecia in the dry chambers, whereas in a third trial aecia formed on the plant in the wet chamber before they did on either the plant held under dry conditions or on the check.

EFFECT OF FREEZING ON RUSTED BARBERRY

Under natural conditions infected barberries frequently are subjected to wide extremes of temperature. The leaves often unfold and become infected during warm weather in the early spring and may be exposed later to freezing temperatures. Experiments therefore were made to determine the effect of low temperature on the rust in infected plants.

Plants of *Berberis vulgaris*, some bearing aecia of the *tritici* variety and some bearing those of the *secalis* variety, were exposed to freezing temperatures in low-temperature rooms. One plant was left in the greenhouse as a check, one was held at 0° C. for 11 days, one was held at 0° for 10 days and at −5° for 24 hours, and the fourth was held at

0° for 10 days, −5° for 24 hours, and −10° for 24 hours. The plants held at −5°, −10°, and −26° were placed at 0° for 24 hours after being frozen, in order to allow them to thaw out before being removed to the greenhouse.

After the removal of the plants from the 0° C. room, the aeciospores from each plant were used to inoculate a susceptible host. Little Club wheat was used for the *tritici* variety and Petkus rye for the *secalis* variety.

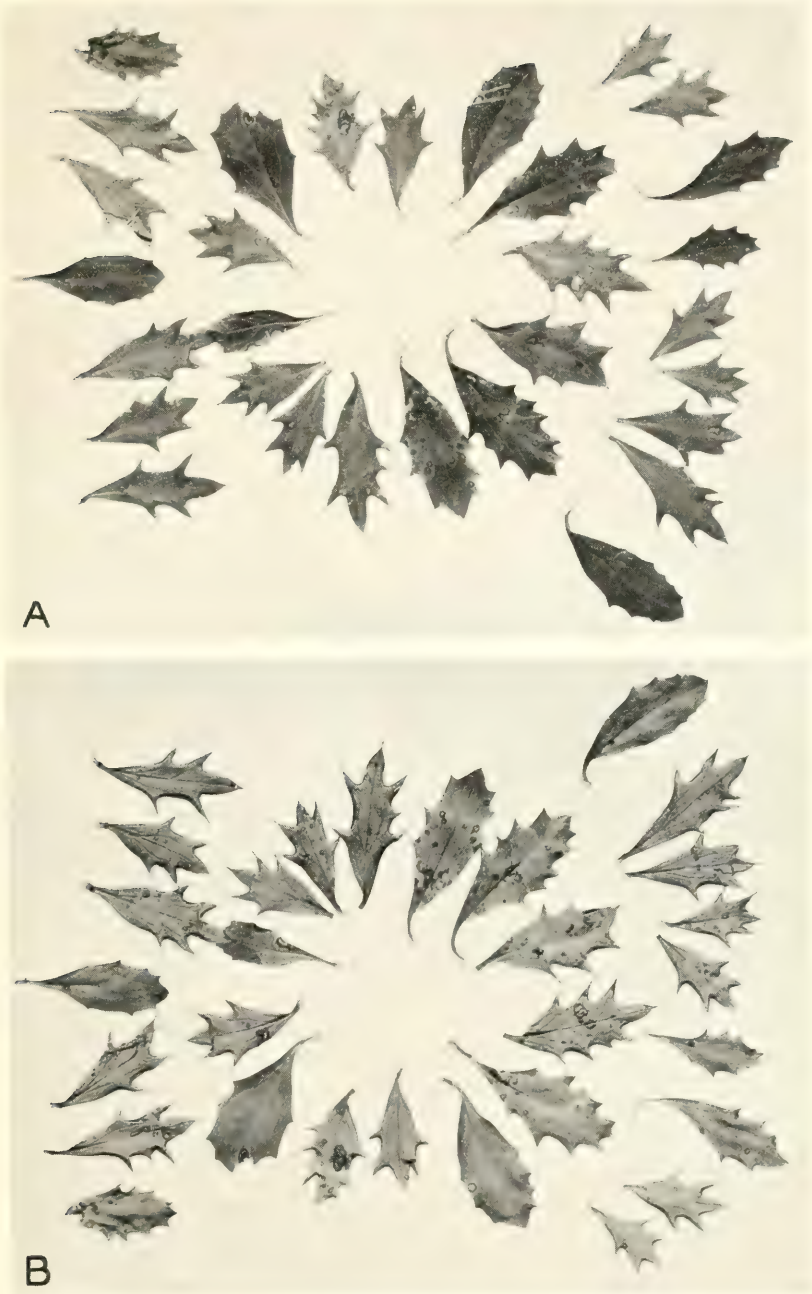
Only one uredinium resulted from the inoculations. This was on Petkus rye inoculated with aeciospores from the plant kept at 0° C. and only 1 plant out of 17 became infected. It is evident, however, that a temperature of 0° did not destroy the ability of the aeciospores to germinate. Craigie [8] found that some aeciospores germinated after having been exposed 70 minutes to a temperature of −6°. As the aecia used in these experiments were from 51 to 67 days old when the plants were removed from the cold rooms, it is more than likely that many of the aeciospores had lost their viability even before they were frozen. As no other aecial material was available at the time, the experiment was not repeated.

A number of *Berberis vulgaris* plants bearing pycnia were likewise subjected to subzero temperatures. One plant was held at 0° C. for 5 days, another for 10 days, a third at −5° for 11 days, and two others were held at 0° for 10 days, −5° for 24 hours, and −26° for 20 hours.

In both the aecial and the pycnial experiments all the plant parts above ground were killed at −5°, −10°, and −26° C., although new leaves subsequently appeared on the plants frozen at −5°. At 0° some of the tender shoots were killed, but new leaves appeared later on the older stems. All the barberry leaves in the aecial series and all the young leaves in the pycnial series were killed at 0° except one of the leaves on the plant bearing pycnia, which subsequently produced a normal aecium. This aecium formed 12 days after the plant had been removed from the 0° room, while aecia developed on the check plant 6 days after the other plants had been removed from the freezing rooms. From this fact it would appear that the rust fungus can live at a temperature as low as the host can withstand, for the rust was able to complete its development when the barberry was placed under favorable conditions, even after having been held at a temperature that killed the younger leaves on the plant.

In a later experiment two series of four plants each of *Berberis vulgaris* were inoculated with sporidia at 16° to 18° C. and then placed in the 0° C. room. At the expiration of a week one of the plants was removed and placed in a greenhouse at a temperature of about 20° C., and four days later a pycnium appeared on one of the young leaves that had not been killed. The second plant in the first series was removed from the 0° C. chamber two weeks after having been placed there. Pycnia appeared three days later. Some time afterwards ammonia escaped from the cooling system and killed the leaves; therefore, three of the six remaining plants were removed from the cold chamber 16 days after being placed therein, and the remaining plants were removed 18 days later. There was no infection on the leaves that later unfolded on the first three plants, but a pycnium appeared on a leaf spine and another on a petiole of one

[8] CRAIGIE, J. H. THE LIBERATION, GERMINATION, AND VITALITY OF THE AECIOSPORES OF PUCCINIA GRAMINIS. [Unpublished thesis, Univ. of Minn. 1925.]



Leaves of *Berberis asiatica* showing pycnial infection produced by *Puccinia graminis tritici*. A, Upper side of leaves; B, lower side of leaves, showing failure of aecia to form from the pycnia. (Photographed 66 days after appearance of pycnia)

of the three plants last removed from the cold room and subsequently kept at 20° C. In another set, nine barberry plants were exposed to rusted *Agropyron repens* straw from Minneapolis, Minn. After removal from the incubation chambers one plant was placed in the greenhouse as a check and the others were placed in the 0° C. chamber, being removed successively at the end of 9, 14, 21, 28, 35, 42, and 49 days. No infection was observed on the plants held 35, 42, or 49 days in the cold room; the leaves were killed and no infection appeared on the leaves that unfolded later in the greenhouse. Pycnia, however, appeared on the plants that were held 9, 14, 21, and 28 days in 12, 7, 3, and 5 days, respectively, after being removed from the 0° C. chamber.

To test the resistance of the mycelium further, four plants with heavy pycnial infection on the leaves were used. On one plant, kept in the greenhouse as a check, aecia appeared 13 days from the time of removal from the incubation chamber. The other three plants were placed in the 0° C. chamber and were removed successively after the expiration of 8, 28, and 91 days. Aecia appeared on the 8-day and 28-day plants 10 days after their removal. The pycnia on the plant exposed 91 days were dry when the plant was removed from the cold chamber, but nectar reappeared 10 days later, followed by the formation of aecia on 8 of the 16 infected leaves 20 days after their removal from the chamber.

Eight other common barberry plants were inoculated with teliospores of *Puccinia graminis secalis* from Chatfield, Minn., and after pycnia had appeared they were placed in the 0° C. room. They were removed 8, 14, 21, 28, 35, and 61 days later. Aecia appeared on the plants held 8, 14, 21, 28, and 61 days, but not on the 35-day plant. The pycnia on the plant exposed 61 days were dry when removed but subsequently produced more nectar, and aecia formed normally.

Thus it appears that barberries that have been infected may not show any visible sign of the presence of the rust for relatively long periods of time during cold weather, but pycnia may appear when conditions become favorable. In line with this evidence, an observation made in the field may be of interest. On May 3 pycnia were observed on *Berberis alesuthensis* at University Farm, St. Paul, Minn. Three days later pycnia also appeared on *B. vulgaris* near by. The weather then became cool. On May 23 aecia had formed on *B. alesuthensis* and were just appearing on *B. vulgaris*. It therefore required 20 days for the appearance of aecia, about four times as long as usually is required under favorable conditions.

From the data presented it would appear that in nature the rust may infect barberries about the middle of April, produce pycnia early in May, and develop aecia the latter part of the month under the retarding influence of low temperature. This also would indicate that the teliospores are ready to germinate at the time of the first spring rains and that the barberries may be infected even while in the bud, although the infection may not become apparent for weeks if low temperatures prevail. In the field, infections occasionally have been observed on the leaf spines of escaped common barberries, indicating that sporidia were being produced even before the leaves unfolded.

EFFECT OF LIGHT ON DEVELOPMENT OF AECIA

To determine whether light has any influence on the development of aecia, a number of barberries were inoculated by means of a shower of sporidia and placed on the greenhouse bench until pycnia appeared. The infected barberries were placed under the following conditions of light: Constant light, constant darkness, and alternate light and darkness. A dark chamber was improvised, consisting of a metal cylinder sunk in the sand of the greenhouse bench and covered by a pane of glass painted with a black, light-proof paint.

All the plants used were moderately or heavily covered with pycnia at the time they were subjected to the various light conditions, and data were taken on the first appearance of aecia. These data are given in Table 10. It would appear that light alone influences the production of aecia very little, although Lambert (*10*) states that "the development of aecial infection after penetration (of sporidia) appeared to be favored by intense light." While aecia usually appeared first on plants kept constantly in the light, in some cases they appeared equally early on those exposed to alternate light and darkness, and in two cases they appeared first in total darkness. It is thought, therefore, that light exercises only an indirect influence. Plants kept in the darkness became etiolated, and the infected leaves were much distorted. Infection was far heavier on the petioles of the barberry plants kept in darkness than on those kept in the light, because the petioles did not become so tough in the dark as under normal conditions. These results corroborate those of Melander.[9]

TABLE 10.—*Influence of light on development of aecia on Berberis vulgaris on which pycnia had been produced after inoculation with Puccinia graminis secalis*

Series No.	Time required for formation of aecia, and degree of infection[1]			Series No.	Time required for formation of aecia, and degree of infection[1]		
	Constant light[2]	Constant darkness	Alternate light and darkness		Constant light[2]	Constant darkness	Alternate light and darkness
	Days	*Days*	*Days*		*Days*	*Days*	*Days*
1	9+	0	11+	4	10++	9+	11++
2	6+	0	6+	5	13++	0	8+
3	10+	9++	11++	6	12+	0	13+

[1] ++, Heavy; +, moderate; +−, light; 0, none.
[2] Constant light consisted of sunlight in the daytime and the rays from a 1,000-watt Mazda lamp suspended 3 feet above the plants at night.

CONDITIONS FOR LIBERATION OF AECIOSPORES

The potential rôle of barberries in initiating rust epidemics depends, of course, upon the time they become infected, the number of spores produced on them, and the distance to which the aeciospores are disseminated from them. The liberation of the aeciospores is prerequisite to their dissemination. It is known that they are forcibly ejected from the aecial cups, but the conditions under which they are discharged are not precisely known. Craigie [10] states: "Moisture is necessary to induce rapid spore liberation. The greatest activity takes place in a saturated atmosphere." This being

[9] Melander, L. W. Op. cit. (See footnote 6.)
[10] Craigie, J. H. Op. cit. (See footnote 8.)

true, the circumstance favors the pathogene, because the spores will be liberated most abundantly when the best condition for infection, that is, a saturated atmosphere, prevails. The writer therefore made observations to determine the conditions under which the aecia open and discharge spores most readily. Fourteen aecial cups of various ages were placed in a Petri dish, on the bottom of which was placed a moist filter paper. Forty minutes later 2 of the aecial cups had opened; 55 minutes later 3 had opened; 65 minutes from the time the experiment was begun 5 of the aecia had opened; 2 hours and 20 minutes later 7 of the 14 had opened and 1 of the cups was discharging spores; and 5½ hours later 10 of the 14 cups were open and 2 were discharging spores. Nineteen hours later 11 of the 14 aecia were discharging spores and the other 3 were open.

It was desirable that the age of the aecial cups be known, for aeciospores are capricious in germination and in viability. Aecial cups of known ages were taken from two series of *Berberis vulgaris* plants inoculated with sporidia of *Puccinia graminis secalis* and placed in moist chambers. Notes were taken on the time required for the aecial cups to open and discharge spores. The results are given in Table 11.

TABLE 11.—*Influence of age of aecia on their opening and the subsequent discharge of aeciospores in a moist chamber* [1]

Series No.	Age of aecia	Aecia	Hours in moist chamber	Aecia		Series No.	Age of aecia	Aecia	Hours in moist chamber	Aecia	
				Opening	Discharging spores					Opening	Discharging spores
	Days	*Number*	*Number*	*Number*	*Number*		*Days*	*Number*	*Number*	*Number*	*Number*
1	15	5	3	3	3	1	37	5	3	[2] 3	2
	18	5	3	[2] 4	1	2	29	8	6	8	1
	22	7	3	7	1		30	14	6	13	1
	24	2	3	[2] 2	0		32	13	6	13	2
	24	4	3	[2] 4	0		33	16	6	16	8
	25	1	3	1	0		37	4	6	4	0
	36	6	3	[2] 5	1		39	9	6	8	0
	37	7	3	[2] 7	0						

[1] Aeciospores of *Puccinia graminis secalis* only.
[2] Cups crumbled without discharging spores, except as indicated in last column.

Aecia that were 24 and 25 days old failed to eject aeciospores forcibly in the first series, while aecia 15, 18, 22, and 36 days old did violently discharge aeciospores in a moist chamber. Among those that were 37 days old there were some from which the spores were forcibly discharged and others from which they were not.

In the second series, aecia that were 37 and 39 days old failed to discharge aeciospores, while aecia 29, 30, 32, and 33 days old did forcibly discharge aeciospores in a moist chamber.

It is evident that the various aecial cups from the same plant vary in their ability to discharge aeciospores in a moist chamber, but in the foregoing experiments some aecia discharged their spores 37 days from the date of appearance of aecia on the barberries. Under natural conditions this circumstance would give the fungus a greater chance to complete its life cycle by infecting grains or grasses. Under fairly dry conditions the aecia on the barberry leaves would remain dormant, while under the moist conditions sometimes present the

aecia would open and discharge the aeciospores, which then would have a much better chance of infecting grains or grasses than if discharged under dry conditions.

VIABILITY OF AECIOSPORES

In order to test the viability of aeciospores formed under greenhouse conditions, Petkus rye was inoculated with aeciospores of *Puccinia graminis secalis* from the living plants at various times after their formation. Three different telial collections were used to produce the aecia. After the rye was inoculated with the aeciospores it was placed in the incubator for 48 hours, then removed and placed on the greenhouse bench in a booth free from other sources of inoculum. The results are given in Table 12.

TABLE 12.—*Effect of age of aeciospores of Puccinia graminis secalis on infection of Petkus rye*

Age of aeciospores (days)	Plants		Age of aeciospores (days)	Plants	
	Inoculated	Infected		Inoculated	Infected
	Number	*Number*		*Number*	*Number*
8	31	16	29	25	6
20	25	6	29	30	9
22	35	7	33	31	13
28	37	25	36	19	0
29	28	0	46	48	5
29	29	1	74	22	0

No infection was obtained with aeciospores of the Rochester (Minn.) collection, which were 74, 36, and 29 days old, respectively, at the time they were used as inoculum, although other spores 29 and 46 days old caused infection. The numbers of plants infected were 1 out of 29 and 5 out of 48, respectively.

When the plants of Petkus rye and Little Club wheat were removed from the incubators after inoculation with aeciospores, the hard, horny aecial cups had been transformed into a flocculent mass of spores. Microscopic examination failed to disclose any germination at this time, and the spores floating on the surface of distilled water failed to germinate two days later. It seems that these aecia crumbled and did not discharge aeciospores. The aecial chains separated from one another and finally broke up without germination of the spores. This phenomenon has been observed in aecia a month old or older and apparently is a sign of age in the aecia.

Uredinia were produced on 4 of 31 plants inoculated with 33-day-old aeciospores from Hennepin County collections. Flecks appeared on leaves of 9 other plants.

Using aeciospores from an unknown source, infection was obtained 8, 20, 22, 28, and 29 days after the date of formation of the aecia. The numbers of plants infected were as follows: 15 of 31 with 1 flecked, 5 of 25 with 1 flecked, 5 of 35 with 2 flecked, 23 of 37 with 2 flecked, 7 of 30 with 2 flecked, and 6 of 25 with none flecked, respectively.

The aeciospores in the foregoing experiments differed in their ability to infect Petkus rye, but infection occurred on this susceptible host with spores from aecia that were 46 days old. Thus, the chances for infection of grains or grasses are much greater than if the aeciospores

were relatively short-lived, in which case they might be liberated in the spring at periods when no susceptible hosts were present and no infection would occur. When the aeciospores are liberated and remain viable for relatively long periods, their chances of falling on susceptible hosts are much greater.

As stated previously, these experiments were made in the greenhouse. Whether the results would have been the same under field conditions is not known, but it seems logical to assume that in the field the aeciospores would not have lived so long, because, exposed to rain and dew, they probably would have germinated more promptly.

PHYSIOLOGIC FORMS WITHIN A SINGLE AECIUM

Even if aeciospores are successfully liberated from the aecial cups and disseminated, the question of their infective capacity still remains. Barberries usually become infected from the near-by grains or grasses. Obviously, if barberries are infected with a variety or physiologic form of rust that will not attack the gramineous hosts near the bushes, epiphytotics will not develop near them, and it may be assumed that the source of the barberry infection was some distance away from the infected barberries. It is therefore important to know which varieties and physiologic forms predominate on the barberry in order better to understand the occurrence of rust in any year.

There is a possibility, of course, that hybridization may occur on barberries. It seemed desirable, therefore, to analyze the parasitic capabilities of the spores within single aecial cups. For this purpose telia on Red Sask wheat were used as the inoculum for susceptible barberries, and the resulting aeciospores constituted the source of all the cultures identified in this work. This telial material was secured from Olaf S. Aamodt, formerly associate pathologist in the Division of Cereal Crops and Diseases, Bureau of Plant Industry, stationed at University Farm, St. Paul, Minn. He stated that the material was the result of inoculation with nine known physiologic forms of *Puccinia graminis tritici*, namely, forms 1, 18, 19, 21, 23, 29, 33, 36, 39, and with some unidentified material collected in the spring-wheat region. Some physiologic forms, e. g., form 21, produce telia rapidly on Red Sask, even in the greenhouse, so the wheat was heavily rusted with telia. The rusted wheat was kept out of doors exposed to the weather during the winter, but the teliospores were found to be viable in April, when some of the barberry inoculations were made. Two of the species, *Berberis declinata oxyphylla* and *B. canadensis*, were heavily rusted. Two cultures of Little Club wheat were inoculated with aeciospores from *B. declinata oxyphylla*, and heavy infection occurred on the majority of the plants in both cultures. One culture was given to M. N. Levine and J. M. Wallace for identification. The writer identified the rust on plants in the other culture. Levine and Wallace identified the rust given them as a new form, *P. graminis tritici* form 51. The author found that the collection he identified comprised a mixture of *P. graminis tritici* forms 18 and 33. In Wallace's collection there was evidence of form 18 also, although it was not completely isolated and identified. These collections or strains were the result of inoculation with aeciospores from a number of aecia.

Four pot cultures of Little Club wheat, one of Manchurian barley, and one of Petkus rye were inoculated with spores from single aecia

from *B. canadensis*. The cups were picked off with a pair of tweezers and placed on the wetted leaf, one cup to a leaf. The six cultures were incubated 48 hours in the usual manner, then placed on the greenhouse bench. The amount of infection varied. In the case of culture No. 1 of Little Club wheat, 2 out of 21 leaves were infected; culture No. 2, 4 out of 19; culture No. 3, 4 out of 15; and culture No. 4, 5 out of 22. One flecked plant was noted in No. 1, 3 flecked plants in No. 3, and 2 flecked plants in No. 4. Of the barley plants, 2 out of 21 were susceptible, while 1 was flecked. None of the Petkus leaves proved susceptible, although two of the leaves were flecked.

The rust on each of the susceptible leaves was treated as an individual strain, and an effort was made to inoculate a susceptible host from each leaf, then isolate the culture of rusted plants and identify this rust as a separate unit. The results are given in Table 13. Because of the press of work, not all of the strains were kept in culture. Consequently, only 10 of 17 possible strains were identified. From these 10 strains, five physiologic forms of *Puccinia graminis tritici*, with a possible sixth, were isolated, in which the technic of Stakman and Levine was followed (*16*).

Study of the data obtained reveals the fact that forms 18 and 35 were found associated in the rust strains five times, forms 21 and 33 occurred together four times, forms 18 and 33 twice, forms 21 and 35 three times, and forms 34 and 35 once. Forms 34, 36, 51, and 52 appeared but once during the course of the investigation, form 51 appearing in the multisorous culture identified by Wallace and Levine, and forms 34, 36, and 52 appearing in the single-cup cultures identified by the author. Form 51 was not known before it was identified by Wallace and Levine in the mass-aecial culture. Form 52 was identified twice in 1928 from field collections, one of which was from northern Minnesota, and it was also in culture at St. Paul in another greenhouse at the time it was identified, so the possibility of its having been a contamination can not be dismissed entirely.

TABLE 13.—*Physiologic forms of Puccinia graminis tritici isolated from Berberis spp., inoculated with teliospores produced on Red Sask wheat grown at University Farm, St. Paul, Minn., 1926*

Source of culture	Aecial host	Rust[1] strain	Number of times physiologic forms indicated were isolated							
			18	21	33	34	35	36	51	52
Many sori	B. declinata oxyphylla	1	1	------	1	------	------	------	------	------
		2	[2] 1	------	------	------	------	------	1	------
Single cup	B. canadensis	LC-1a	------	[2] 1	1	------	------	------	------	------
		LC-2a	------	1	[2] 1	------	------	------	------	------
		LC-2b	1	[2] 1	------	------	[2] 1	------	------	------
		LC-2c	1	------	------	------	[2] 1	------	------	------
		LC-3a	------	1	1	------	------	------	------	------
		LC-3d	1	------	[2] 1	------	1	1	------	------
		LC-4c	[3] 4	[4] 2	1	------	[4] 4	------	------	------
		LC-4g	[2] 1	------	------	------	1	------	------	------
		B-1a	------	------	------	1	[4] 3	------	------	------
		B-1b	------	[2] 1	------	------	1	------	------	[2] 1

[1] LC=Little Club wheat; B=Odenbrucker barley. Numbers refer to primary host; letters following numbers refer to rust strain from each host.
[2] Identity not definitely established.
[3] Identity of all but 1 of the cultures doubtful.
[4] Identity of 1 of the cultures doubtful.

The experiment indicates that when the telia used for inoculating barberry contain more than one form it is improbable that only one form can be secured by using single aecial cups. To be sure of having only one form present in the culture, it would be necessary to use only single chains of aeciospores, or better still, single aeciospores from a single aecial cup. The results obtained suggest the possibility that forms 51 and 52, and perhaps form 34, originated through hybridization on the barberry. As some of the collections of uredinia used in inoculating the Red Sask wheat had not been identified before Aamodt used them, the possibility can not be excluded that forms 34, 51, and 52 may have been present in the field and passed through the barberry unchanged. However, form 51 has never been identified before or since, so it seems strongly probable that it was the result of hybridization. The presence of two or more forms in the strains from single aecial cups indicates that the aecia are not the product of the fusion of the hyphae of a single form at the base of the aecium. If two or more physiologic forms make up or form a single aecium, then, theoretically, there is almost no limit to the number of physiologic forms of stem rust that may be identified in the progeny of a single aecium.

In the rust forms identified from these various cultures not more than two physiologic forms usually were present. In one culture, LC–4c, forms 18, 21, 33, and 35 were definitely identified. In this culture, supposedly derived from a single aecium, four different physiologic forms were present. When several forms are obtainable from a single aecium it is most probable that hybridization will sometimes occur and possibly evolve new forms, or yield forms already known. This may have been the explanation of the appearance of forms 34, 51, and 52. Form 51, new, differs from form 33 only in its reaction to Vernal emmer of the differential hosts. Vernal is susceptible to form 51 and highly resistant to form 33. Form 52 differs from another of the identified forms, form 18, on but 2 of the 12 differentials. Kubanka shows an X-type reaction to form 52, and Vernal is susceptible; Kubanka is susceptible to form 18 and Vernal is highly resistant. Both these forms may have originated as the result of a slight change in the chromosomal arrangement of the cells, one form acquiring the ability to attack Vernal emmer, the other having two factors altered, enabling the pathogene to attack Vernal and produce an indeterminate reaction on Kubanka. It is possible that this indeterminate reaction on Kubanka or some other host is the result of a heterozygous condition of the rust. Inoculating barberry with telia of such a heterozygous rust might break up the rust into two forms, one of which would be able to attack Kubanka severely, the other unable to produce more than a light infection on the same host.

Of the known physiologic forms of *Puccinia graminis tritici*, used to inoculate Red Sask wheat during the summer and fall, only four were isolated the following spring. These were forms 18, 21, 33, and 36. Those not identified in the summer and found in the spring were forms 34, 35, 51, and 52. However, it should be remembered that some unidentified material also was used in inoculating the Red Sask wheat, so the possibility of their presence in the unknown material can not be excluded.

DISCUSSION

It is evident from the foregoing experiments and observations that most of the species of Berberis tested are susceptible to *Puccinia graminis*. Susceptible species in general resemble *Berberis vulgaris* morphologically; those that did not rust resemble *B. thunbergii*. This also was true of the limited number of progeny of *B. vulgaris* × *B. thunbergii* that were tested.

The infection produced on barberries depends upon a number of factors: Age of teliospores, length of incubation period, temperature, age of barberry leaves, and moisture available for germination of teliospores. Teliospores a year or more old produced fewer sporidia than those collected in early spring, as judged by the barberry infections. Teliospores kept cool and dry retained their ability to infect barberry for a year and a half; when exposed to natural conditions the spores lost their viability within a few weeks. Teliospores wetted continuously for 11 days germinated and the resultant sporidia infected the barberry plants. This is significant in nature because teliospores often are exposed to rains before the barberry leaves have unfolded, and if all of them germinated promptly at such times the amount of effective inoculum would be greatly reduced. Barberries may be infected by viable sporidia from teliospores at any time during an 11-day period of rainy weather, provided the temperature is favorable, for there may be a constant discharge of sporidia during this period. The telial material retains its infective power for some time, even when exposed to continuous moisture, and may retain it longer under conditions of intermittent rain.

The minimum length of time necessary for infection of barberries, including germination of the teliospores, formation and liberation of the sporidia, and the entrance of the sporidial germ tubes into the plants, was 41 hours when the teliospores were removed from the straw before inoculation and 21 hours when the plants were inoculated with heavily rusted straw. Plants exposed five hours to a shower of sporidia in an incubator became infected. The length of time required for infection, as well as the severity of infection, depends on a number of factors, the principal ones of which are moisture and temperature. It was found that teliospores do not germinate, produce sporidia, and cause infection readily at temperatures higher than 26° C. The optimum temperature for the entire process required for infection of barberries is fairly low, lying between 12° and 21°. After infection once occurs, temperature again is important in determining the length of the incubation period. Aecia are produced most rapidly at temperatures ranging between 20° and 30°, and the incubation period may be lengthened from 3 days at 31° C. to 15 days at 8°. Moisture has very little effect on the degree of infection, and sunlight in the greenhouse apparently has only an indirect effect. It probably is important principally in the hardening of the leaf tissues. If there is abundant light, the tissues are likely to harden rather rapidly and the period of their susceptibility is shortened. When, on the other hand, there is relatively little light, the tissues remain more delicate and the period of susceptibility is lengthened, as in the case of the petioles of barberry leaves kept in constant darkness.

Leaves, young stems, spines, petioles, peduncles, sepals, and berries may become infected. The impression has been general that leaves

retain their susceptibility only a few days. If this were true, it would be necessary that conditions for infection be favorable when barberry leaves first unfold in the spring. It has been found, however, that leaves of *Berberis vulgaris* may remain susceptible 16 days after the buds unfold. Leaves of *B. aetnensis* may remain susceptible for 12 days; actually this period probably is longer than that for *B. vulgaris*, as there were indications that leaves of *B. aetnensis* were not becoming resistant with increase in age as was the case with *B. vulgaris*. This period of susceptibility during which infection may occur if environmental conditions are favorable is fairly long.

Barberries often become infected quite early in the spring and may therefore encounter freezing temperatures. If such temperatures were more harmful to the rust than to the barberry tissues, the amount of potential inoculum produced on barberries would be greatly reduced in the spring. It was found, however, that freezing kills the tissues of the host plant before it kills the rust fungus. Barberries with a moderate development of pycnia on the leaves were kept 91 days at a temperature of 0° C., but when they were again placed on the greenhouse bench the fungus was able to produce normal aecia. It is therefore apparent that the rust on the barberry can withstand temperatures as low as those endured by its host.

After aecia are once formed in nature there often are periods of dry weather. During these periods the aecia may remain capable of discharging viable spores for 37 days after the appearance of the aecia on the plants. This means, then, that the aecia may remain dormant on fairly dry leaves and resume activity when the air becomes moist enough to enable the aecial cups to open and discharge spores. As the aeciospores are discharged only under moist conditions and germinate only in a moist atmosphere, the rust fungus can withstand unfavorable conditions for some time in the aecial stage. Under greenhouse conditions the aeciospores remained viable as long as 46 days after the date of their appearance on plants of *Berberis vulgaris*.

The results show that the aecial stage of *Puccinia graminis* is fairly well adapted to withstand the variable weather conditions so likely to occur in the barberry-eradication area in the spring. There are a fairly long time and a wide range of environmental conditions under which the aecial stage may develop, discharge spores, and cause infection on grains and grasses.

The recent discovery of heterothallism by Craigie (*4*) has strengthened the belief that hybridization between rust forms may occur on the barberry. The writer's results with cultures of *Puccinia graminis tritici* from single leaves inoculated with individual aecial cups indicate that in telial collections containing more than one physiologic form there is a possibility of new combinations of the known forms. As many as four physiologic forms were isolated from one culture. If four different physiologic forms can be isolated from a culture it is highly probable that at some time some of the physiologic forms in the collection may fuse to form entirely new combinations or physiologic forms. In this work one such form, form 51, was obtained, and another, form 52, was isolated, although form 52 was found in the field the year following the collection of the telia. Form 51 never has been described, so it is very probable that this form originated on the barberry through hybridization of other forms.

The work of Newton, Johnson, and Brown (*14*) and Stakman, Levine, and Cotter (*17*) on hybridization in *Puccinia graminis* involved making many cultures from single aecia. From conversation with Newton it appears that individual unopened aecia were used, and very rarely did more than one physiologic form appear in any one culture. In the writer's results it was unusual to find but a single physiologic form present. This obvious discrepancy in the results may perhaps be explained by the fact that in the writer's experiments at least nine known physiologic forms, and probably more, were present in the telial collection used to inoculate the barberries from which the uredinial cultures were derived. In the experiments of Newton et al. only one or two forms were present in their telial material.

SUMMARY

A study was made of the factors affecting the development of the aecial stage of *Puccinia graminis*.

A list of susceptible and immune species and varieties of Berberis, as determined by the writer and others, is given.

In individuals from a *Berberis vulgaris* × *B. thunbergii* cross there seemed to be a correlation between the morphologic characters of *B. vulgaris* and susceptibility to *P. graminis*.

Teliospores of *P. graminis* may remain viable at least a year and a half when kept dry and at a temperature near the freezing point.

Teliospores of *P. graminis* do not germinate and produce sporidia at temperatures higher than 26° C., or if they do, they do so very rarely.

Barberries may become infected when exposed to teliospores that have been wetted for 264 hours, or 11 days.

Temperatures ranging from 12° to 21° C. are the most favorable for the germination of teliospores, infection of barberry bushes, and production of aecia. Freezing infected barberries killed the host plant before it killed the rust.

Light and moisture had no decided effect on the production of pycnia or aecia, although there was some evidence that the absence of light may increase and prolong the susceptibility of barberry leaves because the tissues remain succulent.

The minimum length of time necessary for barberry infection by teliospores was 21 hours, although infection occurred after a 5-hour period of exposure to a shower of sporidia in a moist chamber.

On *Berberis vulgaris*, infection may occur on the leaves, stems, spines, petioles, sepals, or berries.

Leaves of *B. vulgaris* 16 days old were susceptible to the attack of *P. graminis*.

Aecia of *P. graminis* may discharge aeciospores 37 days after the appearance of the aecia, and the aeciospores may infect rye 46 days after the appearance of the aecia on the barberry leaves.

Two physiologic forms of *P. graminis tritici* were isolated from a number of uredinial cultures produced by single aecial cups, although the forms found were not the same in all cultures. In one case four physiologic forms were identified from such a culture. The telia used to inoculate the barberries contained nine or more physiologic forms.

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STUDIES ON PHYSIOLOGIC SPECIALIZATION IN PUCCINIA TRITICINA[1]

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CONTENTS

	Page
Introduction	1
History	2
Materials and methods	3
Differential or standard varieties	3
Methods of study	5
Infection types and reaction classes	7
Experimental results	10
Coordination of published and new data dealing with physiologic specialization in *Puccinia triticina*	10
Experimental results—Continued.	
Relationship and variations of physiologic forms	13
Distribution and prevalence of physiologic forms of *Puccinia triticina* in the United States and Canada	15
General discussion	19
Summary	21
Literature cited	21

INTRODUCTION

The problem of physiologic specialization in parasitic fungi continues to be one of vital interest to plant pathologists and plant breeders everywhere. Although the urge to discover new physiologic forms merely to increase the number in any particular species is rapidly diminishing, it is impossible to escape the practical necessity of continually searching for, describing, and cataloguing new forms. Modern plant breeding rightfully demands this knowledge as an invaluable aid in the production of improved disease-resistant varieties of crop plants.

Although Mains and Jackson (*10*) [3] described 12 physiologic forms of the leaf rust of wheat, *Puccinia triticina* Eriks., in 1926, it was realized at the time that these comprised only a few of the forms present in the United States, and that the number would require extension from time to time. Since 1926 studies on physiologic specialization have been conducted concurrently at the Purdue University (Indiana) and the Kansas agricultural experiment stations. The data obtained on the occurrence of new physiologic forms are presented in this bulletin, together with a revision and coordination of the data on physiologic forms of *P. triticina* as presented by various writers.

[1] The investigations here reported were conducted by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, in cooperation with the Department of Botany and Plant Pathology of the Kansas Agricultural Experiment Station and the Department of Botany of the Purdue University (Indiana) Agricultural Experiment Station.

[2] The writers gratefully acknowledge many helpful suggestions received from M. N. Levine and H. B. Humphrey during the course of the studies here reported.

[3] Italic numbers in parentheses refer to Literature Cited, p. 21.

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HISTORY

In 1926 Mains and Jackson (*10*) proved the existence of 12 physiologic forms of *Puccinia triticina* through the use of 11 varieties of common wheat as differential hosts. Two years later Scheibe (*13*) described 3 new forms from collections made in central Europe and designated them as forms 13, 14, and 15. He also stated that form 11 was the only one described by Mains and Jackson from North American material found by him in central Europe. In this paper Scheibe unwittingly has introduced an error into the literature on physiologic forms of *P. triticina*. Seed of the differential varieties was furnished him by Mains, but since the publication of his data in 1926 (*10, p. 101*) Mains had discarded Turkey 47 from the list. This was done because the reaction of Turkey 47 to the 12 described forms was the same as that of Malakof (C. I.[4] No. 4898) and because Turkey 47 had a tendency to cross very readily with other varieties in the field. Therefore, seed of Turkey 47 was not sent to Scheibe when he requested seed of the 11 standard varieties. A supply of Michigan Amber 29–1–1–1 was sent him at that time, however, as a very susceptible variety upon which to grow stock cultures. Mains had found Michigan Amber very satisfactory for that purpose because it had proved susceptible to nearly all of the known physiologic forms. Scheibe, however, apparently considered Michigan Amber as a substitute for Turkey 47 and therefore as having the same reactions to forms 1 to 12, inclusive, as Turkey 47. In his paper (*13, p. 593*) he has assigned the reactions of Turkey 47 in Mains and Jackson's data to Michigan Amber 29–1–1–1 for all of the first 12 forms except form 11, for which he gives the reactions he obtained with European rust collections. Michigan Amber 29–1–1–1 has not been shown by published data to have differential reaction to physiologic forms of *P. triticina* and should be eliminated from the list of differential varieties.

Waterhouse (*17*) noted the occurrence of two forms of leaf rust of wheat in Australia in 1929. These forms were interesting in that they had identical reactions on the 11 standard varieties used by Mains and Jackson. However, when the Australian variety Thew was added to the list it was found that there were really two forms, to one of which Thew was resistant, while to the other it was susceptible. Although Waterhouse thus described two new physiologic forms, he did not give them definite numbers, merely designating them as "Aust. 1" and "Aust. 2."

In May, 1930, another paper by Scheibe (*14*) increased the number of known physiologic forms of *Puccinia triticina* to 23. Forms 16 to 23, inclusive, were described from collections made in Germany, Latvia, Estonia, Poland, Bulgaria, and Hungary in 1928 and 1929. Scheibe's studies indicated that in Europe there are two main groups of physiologic forms, a west-European group composed of 5 forms and an east-European group of 7 forms. He points out that the west-European group is composed of forms that are relatively "non-aggressive" on the 11 standard varieties, while the eastern group is composed of "aggressive" forms to which many of the standard varieties are highly susceptible.

[4] C. I. indicates accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

Aside from the researches of Mains and Jackson in the United States and those of Scheibe in Germany, data on phsyiologic forms of *Puccinia triticina* are very meager. The two forms described by Waterhouse already have been mentioned. Wellensiek (*18*) studied several collections of leaf rust from different parts of the Netherlands and found three forms —11, 14, and 15—all of which had been found by Scheibe in Germany. Dodoff (*4*) has described a new form resulting from experiments conducted in Bulgaria. Unfortunately, however, he has followed Scheibe's error in considering Michigan Amber a differential variety. Another physiologic form, form 25, has recently been discovered and described in Europe by Tscholakow (*16*). In the United States Johnston (*8*) described an aberrant physiologic form in 1930, and that constitutes the only form described in this country since 1926.

MATERIALS AND METHODS

DIFFERENTIAL OR STANDARD VARIETIES

The varieties used in these studies as differential hosts for the identification of physiologic forms were the same as those originally used by Mains and Jackson (*10*) with the exception of Turkey 47, Norka (C. I. No. 4377), and "unnamed" (C. I. No. 3747), which have been dropped from the list. The unnamed spring varieties were described by C. E. Leighty in the paper by Mains and Jackson (*10*), but no names were given them. Since the varieties are in use in various parts of the world and it is often confusing to refer to several different varieties under the general term "unnamed," it was deemed advisable to name them. The following names, therefore, have been adopted and used in these studies:

Unnamed, C. I. No. 3747=Similis, C. I. No. 3747.
Unnamed, C. I. No. 3756=Carina, C. I. No. 3756.
Unnamed, C. I. No. 3778=Brevit, C. I. No. 3778.
Unnamed, C. I. No. 3779=Loros, C. I. No. 3779.

Although descriptions of these varieties have been given by Mains and Jackson, several distinctive characteristics of some of them are useful in detecting mixtures in the greenhouse or field. Webster (C. I. No. 3780) and Similis (C. I. 3747) are essentially identical in agronomic characters and reaction to physiologic forms of leaf rust. Both are characterized by very weak straw and are inclined to lodge in nursery sowings. Both have long, lax, bearded, somewhat speltoid spikes with extremely long beaks and light-brown glumes. Because of its similarity to Webster in reaction to all known physiologic forms, Similis was dropped from the list of varieties used in the studies herein reported.

Carina develops somewhat stiffer straw in field sowings than either Webster or Similis. It is characterized by white chaff with a distinct keel carried to the base of the glume, and beaks that frequently are as long as the awns, especially under greenhouse conditions.

Brevit is easily distinguished from all of the other spring varieties by its short beak. It also has somewhat stiffer straw than either Webster or Similis, but is inclined to lodge at the time of maturity.

Loros has long beaks, which, in the greenhouse, frequently are as long as the awns. Under field conditions it stands a little better

than Webster, Similis, Carina, and Brevit and is inclined to have darker brown glumes. In the seedling stage, in the greenhouse, this variety often shows a serious physiologic weakness of the leaf tissues of the first seedling leaf (prophyllum) that often makes it extremely difficult to get satisfactory rust readings. This weakness usually is manifested by a somewhat water-soaked appearance of the tissues, even before inoculation. After removal from the moist chamber such areas dry up very rapidly, giving that part of the leaf a scalded appearance. (Fig. 1.) This frequently happens despite the most careful handling. The tissues apparently are very delicate and sensitive to sudden changes in environmental conditions, as well as to even very slight pressure such as occurs in the case of hand inoculations. The scalded areas often embrace the entire area on which spores have been sown, which naturally results in no visible infection. Sometimes the injury begins at the tip of the leaf and covers most of the leaf area. More frequently, however, the injury occurs as large scalded areas near the center of the leaf, leaving areas of normal green tissue at the tip and base.

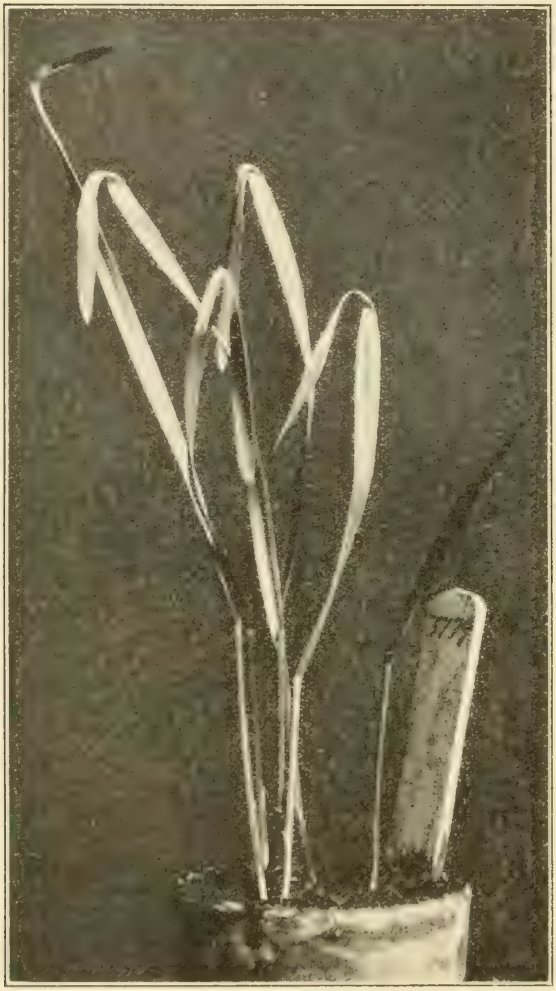

FIGURE 1.—Seedlings of Loros wheat (C. I. No. 3779), showing typical scalding of leaves after removal from the moist chamber

Norka probably possesses the stiffest straw of the spring sorts used in past experiments as differential varieties. It also has a much denser spike and smaller kernels than any of the spring varieties discussed above. Norka was dropped from the list of differential varieties used in the experiments reported in this bulletin because all preceding investigations had shown it to have reactions the same as those of Malakof to all known physiologic forms.

The four winter-wheat varieties used as differentials, viz. Malakof (C. I. No. 4898), Mediterranean (C. I. No. 5332), Hussar (C. I. No. 4843), and Democrat (C. I. No. 3384), are fully described by Clark, Martin, and Ball (*2*).

It has been very difficult to keep pure seed of differential varieties in sufficient quantities for detailed physiologic form testing and to supply other investigators with seed. Considerable natural crossing has occurred in some varieties, and there has been some mechanical mixture owing to threshing and handling of seed in quantities. All of the varieties have been repeatedly pure-lined and tested. From these only the best lines have been retained for use in the United States and sent to investigators abroad. In the writers' experiments several plants of each variety were inoculated with each rust culture and occasional off-type plants were easily identified by their differences in plant characters or reaction to rust. Such plants were recognized as mixtures and discarded from the experiment without further consideration.

METHODS OF STUDY

All the original data presented in this bulletin were secured from experiments conducted with seedling plants in the greenhouses at Manhattan, Kans., and La Fayette, Ind., in the winter and very early spring of the period from 1926 to 1930, inclusive. Rust collections were made in the field at various points in the United States, usually in spring and summer. Uredinial material on green leaves usually was collected. The leaves were dried and stored in glassine envelopes in the refrigerator until needed for greenhouse testing. When ready for use the spores were scraped from the leaf with a small moistened spatulate instrument and either spread directly on moistened leaves or placed in a drop of water on a glass slide, from which they were then transferred to the leaves. Transfers from field collections usually were made to the first seedling leaves of some susceptible variety of wheat such as Turkey or Michigan Amber. The film of water causes the spores to cling readily to the leaf surface when the spatula, covered with moistened spores, is rubbed over the leaf. The lower surface of the leaf seemed to be a little better than the upper surface for this purpose.

The inoculated seedlings were then placed in small moist chambers, the bottoms of which were covered with sphagnum moss that had been thoroughly wet down just before the seedlings were placed upon it. In the earlier experiments the tops of the moist chambers contained a pane of glass to admit light, but this was later found to be unnecessary, and in most experiments the seedlings were in absolute darkness during the infection period. At Manhattan small galvanized-iron cylinders were used for moist chambers, and after the plants were in place several thicknesses of newspaper were placed over the top and thoroughly wet with tap water. A pane of greenhouse glass or a layer of board was placed upon this. The paper cover was wet down twice daily by sprinkling with tap water. This was found to give the required relative humidity inside the moist chambers, and excellent infections resulted, although light was excluded. In the earlier experiments at Manhattan great difficulty was experienced in getting satisfactory infections with any regularity.

Apparently this was due to the very dry atmosphere and the difficulty of maintaining a high humidity in the moist chambers. Spores of *Puccinia triticina* must be in contact with condensed moisture for satisfactory germination. Under proper moist-chamber conditions the leaves should be covered with dew.

Most investigators have followed the practice of keeping plants in the moist chamber 48 hours. There are serious objections to this method because the seedlings often are spindling and etiolated when removed and the tissues are very delicate and tend to scald easily. In the writers' experiments it soon became apparent that, if optimum conditions for infection were provided, perfectly satisfactory infections were obtained in 24 hours in the moist chambers. This not only speeded up the work greatly, but the seedlings came out of the chambers in sturdier condition and were less likely to scald. The seedlings usually were removed from the moist chambers to the greenhouse benches late in the evening when there was no sun on the greenhouse glass to cause scalding.

The stock culture thus established was then transferred to 10-day to 12-day-old seedlings of the differential varieties that had been grown in a separate compartment of the greenhouse where there were no cultures of rust. Occasionally time can be saved by transferring spores directly from the material collected in the field to a set of differential varieties. However, very frequently a field collection either fails to germinate or germinates very poorly, and the whole set of differentials is then lost. When the stock-culture method was used the individual cultures were placed in separate compartments and several tests frequently were made from the original stock. Transfers from stock cultures to differential varieties were made by hand in the same manner as described for the establishment of a stock culture. Rust readings on differential varieties were made when infection was fully developed, which usually varied from about 14 days after inoculation in midwinter to 10 days or less in late spring. During the period of very short days and low light intensity the incubation period often was remarkably long.

If the first test showed a rust collection to be a mixture of physiologic forms, single-spore or single-uredinium transfers were made to seedlings growing under lantern globes with a thin layer of cotton over the top to exclude stray spores. If two or three varieties showed both flecks and uredinia, or had uredinia of different types on the same leaf, pure-culture transfers to plants grown under lantern globes were made from each type. Because of the greater ease of handling and of securing a greater number of successful transfers, a large portion of pure-line cultures came from single-pustule transfers. Well-isolated pustules were selected in making them. The spores were carefully collected on a moistened spatula and transferred to seedlings under lantern globes. Such cultures usually proved to be pure, but if there still was an indication of mixture the process was repeated until pure cultures were obtained. Once a pure-line culture was established, its purity could be maintained indefinitely by transferring it to fresh seedlings under lantern globes.

As already stated, the writers' experiments were conducted only with seedling plants in the greenhouse in the winter and early spring.

All the foregoing conditions are important, as has been demonstrated by various investigators. Johnston and Melchers (*9*) demonstrated that several varieties of wheat reacted differently to leaf rust at different stages of growth. Data secured in these studies clearly show that some of the differential varieties are susceptible as seedlings but resistant at heading time. This change in reaction usually begins on the second, third, or fourth leaf, so that readings made on leaves other than the primary leaf may not be reliable.

It is now a well-known fact that environmental conditions often have a marked effect on the type of reaction exhibited by a variety. Mains and Jackson (*10*) noted that Hussar (C. I. No. 4843) often was highly resistant to a form of leaf rust during the fall and winter and only moderately or slightly resistant to the same form in the late spring. Waterhouse (*17*) found that Thew, Hope, Iumillo, Hussar (C. I. No. 4843–2), and Carina (C. I. No. 3756–4) were susceptible to certain forms of leaf rust in the summer and resistant in winter tests. In studies made during the winter and summer he noted also very marked differences in the behavior of certain differential varieties to forms of *Puccinia graminis tritici* and *P. graminis avenae*. The same was true of a collection of *P. simplex* (*anomala*) on certain varieties of barley. Johnson (*7*), working with stem rust of wheat in Canada, found that increases in temperature tended to change the type of infection of certain physiologic forms on some differential varieties. Gordon (*5*) found the same to be true of the reaction of Joanette oats to forms 1, 3, 4, and 5 of *P. graminis avenae*. Peturson (*12*), working with physiologic forms of *P. coronata avenae*, concludes that several of the differential varieties reacted very differently to several of the forms, depending on the temperature at which the plants were held after inoculation.

Care also must be taken not to confuse effects produced by other causes with those produced by rust infection. Doak (*3*) has shown that the wilting of inoculated plants for a short time will bring about death of infected cells. Susceptible varieties may be made to appear highly resistant, moderately resistant, or of indeterminate reaction, depending on the point in the incubation period when wilting occurred and also on the amount of wilted tissue.

These researches suggest explanations for some of the conflicting results obtained at different times and by different investigators. They also point out the necessity for conducting experiments of this nature under environmental conditions as similar as possible.

INFECTION TYPES AND REACTION CLASSES

Most investigators recognize three main classes of reaction of host varieties to rust, viz, resistant, susceptible, and indeterminate. It also is generally recognized that resistance is expressed by three distinct types of infection, and susceptibility by two such types, although they also may be considered as five types of susceptibility. These can be said to show a gradual gradation from the highest type of resistance to complete susceptibility. (Fig. 2.) These types of infection therefore have been designated by the Arabic numerals 0, 1, 2, 3, and 4, 0 representing the greatest resistance and 4 the highest susceptibility. These types are adequately described for leaf rust by

Mains and Jackson (*10*), and their classification has been adopted in these studies.

Although the heterogeneous type of infection described by Stakman and Levine (*15*) as "type X" was occasionally encountered by Mains and Jackson, it was not described by them nor used in their table of reactions. It was observed and recorded by Scheibe in Germany and Waterhouse in Australia in their studies on leaf rust of wheat. Scheibe used the reaction as distinguishing characteristics of forms 22 and 23, and Waterhouse noted that under certain conditions several of the differential varieties exhibited an "inter-

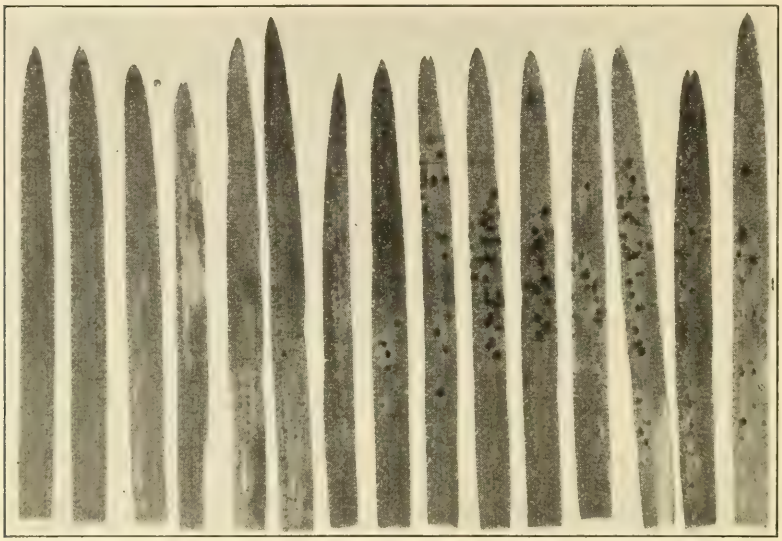

FIGURE 2.—Types of infection produced by *Puccinia triticina* on varieties of wheat. From left to right the types are 0, 0, 0, 1−, 1, 2−, 2, 2+, 3, 3+, 4, X, X, X, and mixed. The latter is a mixture of two forms on the same leaf

mediate type X" reaction to the two Australian forms. Stakman and Levine define the heterogeneous X type as follows:

> Uredinia very variable, apparently including all types and degrees of infection on the same blade; no mechanical separation possible; on reinoculation small uredinia may produce large ones, and vice versa. Infection ill defined.

This is essentially the conception that most investigators have had of the X-type infection. This type of infection very frequently is encountered in F_1 hybrids and heterozygous segregates in later generations, when resistant and susceptible varieties have been crossed. In such a case it is considered an "intermediate" type of reaction. The use of the term "intermediate" would be very useful in certain respects. For example, it was frequently observed in the course of the writers' studies that a certain variety would give a type 2 or 2+ reaction at one time and at a later reading would give a type 3 reaction to the same rust form. In reality, the variety had a reaction varying from moderate resistance to moderate susceptibility, which could readily be considered intermediate. Varieties having a reaction of 2–3 can not be placed in either resistant or susceptible categories, since they actually are intermediate between these two in re-

action. They therefore should be classed as intermediate or variable. The term "variable" is used in this bulletin to designate different reactions of the same variety to the same form at different readings, and the term "indeterminate" to designate the occurrence of type X infection.

There has been one marked difference in the method of presenting data for use in the identification of physiologic forms of the various races of stem rust and for leaf rust of wheat. Stakman and Levine (*15*), Newton (*11*), Bailey (*1*), Waterhouse (*17*), and others have recently used mean infection types alone with modifying symbols for recording slight fluctuations in the reaction of a variety to a form of rust. Mains and Jackson (*10*), Scheibe (*13, 14*), and Dodoff (*4*) have always used the observed range in types of infection instead of means. Each method has several points in its favor. Infection means require less space in tabulation, are more easily recorded, and probably give greater uniformity to cereal-rust literature. Ranges of infection are very useful in that they indicate precisely the limits observed for the recorded form on each variety. They also probably are more readily understood by persons not closely conversant with rust literature who may have occasion to use such data. The data presented in this bulletin therefore are presented in terms of ranges wherever such readings were obtained. It should be borne in mind that where a reaction of 2–3 is indicated other investigators may constantly obtain reactions of type 2 or type 3 for the same form on the same variety. In such cases the data in Table 1 and in the key are applicable even though no variability had been shown.

TABLE 1.—*Reaction of differential varieties of Triticum vulgare*[1] *to physiologic forms of Puccinia triticina*

Physiologic form	Type of infection on wheat variety—								Described by—
	Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat	
1	0	0	0	0	0	1	1	0	Mains and Jackson.
2	0-1	0-1	0-1	0	0-1	4	3-4	4	Do.
3	0-1	0-2	2-2+	0-2	2-4	3-4	0-1	4	Do.
4	0-1	4	4	1	3-4	3-4	2-2+	1-2	Do.
5	4	0	0-1	0-1	0-1	4	0-2+	4	Do.
6	4	2	4	1-2	3	3-4	3	3-4	Do.
7	4	1-2	1	4	1	4	1	4	Do.
8	4	1	4	4	4	3-4	1	1	Do.
9	4	1-2	1-2	4	4	0-1	1-2+	0-1	Do.
10	4	4	4	4	4	1-2	1-2	1-2	Do.
11	0	2+	3-4	1-2	3-4	1-2	0-2	0-2	Do.
12	0	4	4	1	4	4	4	4	Do.
13	4	4	2-	4	4	0	4	0	Scheibe.
14	0	2-	4	1	4	0	4	0	Do.
15	0	0	0-1	0	0-1	4	0-1	4	Do.
16	0	0	0	0	0	0	2	0	Do.
17	4	0	0	0	0	0	4	0	Do.
18	0	4	2	4	4	0	4	0	Do.
19	4	4	2	4	4	0	1	0	Do.
20	4	4	4	4	4	0	4	0	Do.
21	4	4	2	4	4	4	4	4	Do.
22	X	4	4	1-2	4	0-1	0-1	0-1	Do.
23	X	4	2	4	4	0	4	0	Do.
24	4	3-4	1-2	4	4	0-2	4	X	Dodoff.
25	0	2	4	0	2	4	0	4	Tscholakow.
26	0	4	4	0	4	0	4	0	Waterhouse.
27	3-4	2	1-2	3-4	3	2	2-3	2-3	Johnston.

[1] According to the rules of botanical nomenclature the name of this species is *Triticum aestivum*, but as *T. vulgare* is in general use among agronomists, the writers give preference to that form.

TABLE 1.—*Reaction of differential varieties of Triticum vulgare to physiologic forms of Puccinia triticina*—Continued

Physiologic form	Type of infection on wheat variety—								Described by—
	Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat	
28	4	1+	1+	2+	3	4	3	4	Johnston and Mains.
29	4	2-3	2-3	2-3	4	1-2+	3	1	Do.
30	4	2-3	2-3	3	3-4	4	1-2+	4	Do.
31	4	2	1-2	4	4	1-2	3-4	1-2	Do.
32	0	2	X	1-2	3-4	4	1-2	4	Do.
33	0	1	2+	0-1+	4	2+	1	4	Do.
34	0	0	0	0-1	1	4	X	4	Do.
35	4	2+	2+	4	4	4	1	4	Do.
36	2-3	0	0-2	0	0-2	2+	1-2	2+	Do.
37	3-4	2+	2	0-2	3-4	2+	2	2+	Do.
38	0	2-2+	1-2	0-1	3-4	2+	1-2	2+	Do.
39	3-4	2-3	2-3	0-1	4	3-4	0-1	3-4	Do.
40	4	4	2	0	3-4	4	4	2-3	Do.
41	4	2-3	2	4	4	2	2	3-4	Do.
42	4	2-3	3	4	4	3-4	4	4	Do.
43	4	3	3	1-2	4	1	2	1-2	Do.
44	0	2	2	0-2	4	X	0-1	4	Do.
45	0	3-4	2+	4	4	3-4	2	3-4	Do.
46	0-1	2-3	2	0-1	4	2	1-2	3-4	Do.
47	4	3	2	4	0	2	0	2	Do.
48	4	3-4	2	4	4	2-3	2	0	Do.
49	4	3	3	2	3-4	0	4	0	Do.
50	4	2	4	2−	3	0	2	0	Do.
51	0	1	3	1	3	2	3	3	Schaal, Stakman, and Levine.
52	4	0	1	0	1	4	3	4	Do.
53	0	1	2	1	1	0	3	0	Do.

EXPERIMENTAL RESULTS

COORDINATION OF PUBLISHED AND NEW DATA DEALING WITH PHYSIOLOGIC SPECIALIZATION IN PUCCINIA TRITICINA

In order to bring the data on physiologic forms of *Puccinia triticina* into closer harmony, the data on physiologic forms of leaf rust, as reported by Mains and Jackson, Scheibe, Dodoff, Waterhouse, and Johnston are presented in Table 1. The data on 26 additional physiologic forms are also included in this table. It will be noted that three varieties used by other investigators are not included in this table, viz, Norka, Similis, and Michigan Amber. Norka and Similis, as previously stated, are omitted because their reactions to all known physiologic forms are almost identical with those of Malakof and Webster, respectively. Michigan Amber has been omitted because it has shown no differential reaction to any of the known forms. Scheibe found it susceptible to all of the forms found by him in central Europe, and Mains and Jackson used it as a susceptible host for their stock cultures. Since there is also an error in the reactions of the variety to the first 12 physiologic forms as given by Scheibe (*13*), it seems desirable to eliminate it from the list of differential hosts and the reaction record.

With this misunderstanding corrected, there remains the difficulty of distinguishing between physiologic forms 1 and 16. In the key presented on page 11 they are separated only by the slight differences in reaction of Hussar. The reaction of this variety to form 1 is type 1, and to form 16, type 2. There is some question as to the validity of differences as small as this, especially with Hussar, and it is likely that form 16 is actually form 1. For the sake of maintaining the form numbers used by Scheibe, form 16 is included in the data herein presented; but it is felt that it is the same as form 1.

In the designation of forms in Table 1 the numbers of the forms described by Mains and Jackson and by Scheibe have been retained. Although Waterhouse (*17*) had described two forms before Scheibe's (*14*) paper of 1930 appeared, he assigned no numbers to them except "Aust. 1" and "Aust. 2." However, in so far as the standard varieties are concerned, these two forms constitute only a single form. Waterhouse found it necessary to add Thew to the list of varieties to separate the two forms. Dodoff (*4*) also apparently was unaware of the work of Waterhouse and described a form he encountered in Bulgaria as form 24. Tscholakow also has described a new form to which No. 25 has been given. It therefore becomes necessary to place Waterhouse's data immediately after Tscholakow's in Table 1 and to assign No. 26 to his physiologic form. No. 27 was assigned to the aberrant physiologic form described by Johnston (*8*). Forms 28 to 53, inclusive, are forms here described for the first time. Of these, forms 28 to 35, inclusive, were found by E. B. Mains in his experiments at La Fayette, Ind., forms 36 to 50, inclusive, were found by C. O. Johnston in experiments conducted at Manhattan, Kans., and forms 51, 52, and 53 are forms encountered by Schaal, Stakman, and Levine [5] in experiments at St. Paul, Minn.

While every effort was made to simplify the key for identification of forms and to retain its dichotomy, it has been necessary to make use of characters other than the directly opposite resistance and susceptibility. The introduction of the indeterminate and variable types into the data made this a necessity, but it is believed that the usefulness of the key has not been impaired. When the key and the table of reactions are used together, as they must be for accuracy, it is relatively easy to ascertain the physiologic form or forms of a rust collection.

Analytical key for the identification of physiologic forms of Puccinia triticina, determined on the basis of their parasitic behavior on differential varieties of Triticum vulgare

	Form No.
Malakof resistant—	
Carina resistant—	
Brevit resistant—	
Loros resistant—	
Mediterranean resistant—	
Hussar resistant—	
Hussar type 1	1
Hussar type 2	16
Hussar susceptible	53
Mediterranean susceptible—	
Hussar resistant	15
Hussar indeterminate (X)	34
Hussar susceptible	2
Loros variable	3
Loros susceptible—	
Mediterranean resistant—	
Democrat resistant	38
Democrat susceptible	33
Mediterranean indeterminate (X)	44
Brevit indeterminate (X)	32
Brevit susceptible—	
Hussar resistant—	
Democrat resistant	11
Democrat susceptible	25

[5] Unpublished data.

	Form No.
Malakof resistant—Continued.	
Carina resistant—Continued.	
Brevit susceptible—Continued.	
Hussar susceptible—	
Democrat resistant	14
Democrat susceptible	51
Carina variable	46
Carina susceptible—	
Brevit resistant—	
Mediterranean resistant	18
Mediterranean susceptible	45
Brevit susceptible—	
Hussar resistant	4
Hussar susceptible—	
Democrat resistant	26
Democrat susceptible	12
Malakof variable	36
Malakof indeterminate (X)—	
Brevit resistant	23
Brevit susceptible	22
Malakof susceptible—	
Carina resistant—	
Brevit resistant—	
Webster resistant—	
Loros resistant—	
Mediterranean resistant	17
Mediterranean susceptible—	
Hussar resistant	5
Hussar susceptible	52
Loros susceptible—	
Mediterranean resistant	37
Mediterranean susceptible	28
Webster susceptible—	
Loros resistant	7
Loros susceptible—	
Mediterranean resistant—	
Hussar resistant	9
Hussar variable	27
Hussar susceptible	31
Mediterranean susceptible	35
Brevit susceptible—	
Webster resistant—	
Mediterranean resistant	50
Mediterranean susceptible	6
Webster susceptible	8
Carina variable—	
Brevit resistant	41
Brevit variable—	
Webster resistant	39
Webster variable	29
Webster susceptible	30
Brevit susceptible	42
Carina susceptible—	
Brevit resistant—	
Webster resistant	40
Webster susceptible—	
Loros resistant	47
Loros susceptible—	
Mediterranean resistant—	
Hussar resistant	19
Hussar susceptible—	
Democrat resistant	13
Democrat indeterminate (X)	24
Mediterranean variable	48
Mediterranean susceptible	21

Malakof susceptible—Continued.
Carina susceptible—Continued.
Brevit susceptible—
Webster resistant—

	Form No.
Hussar resistant	43
Hussar susceptible	49
Webster susceptible—	
Hussar resistant	10
Hussar susceptible	20

RELATIONSHIP AND VARIATIONS OF PHYSIOLOGIC FORMS

Stakman and Levine (*15*), in the case of stem rust, and Mains and Jackson (*10*), in the case of leaf rust, recognized that the addition of proper differential varieties might make possible the separation of cultures that had previously been considered a single form. Waterhouse (*17*) found that the variety Thew divided form 26 into two forms under certain conditions. Scheibe (*14*) has also pointed out that certain physiologic forms are really closely related members of composite groups. As far as the 11 standard varieties were concerned, they appeared to be a single form but could be differentiated by the reaction of other varieties. The writers' experiments also have frequently indicated that the addition of other varieties to the list of differentials might divide described forms into two or more forms. New forms were not described on such a basis, however.

Many instances of the manifestation of the same phenomenon, in a slightly different way, have also been encountered. It frequently has been observed that two or more forms differ from each other only in the reaction of a single variety. If this difference is high resistance opposed to high susceptibility, it probably is real and constant. If, however, it is between resistance and intermediacy, or susceptibility and intermediacy, there is some doubt as to the actuality of the difference. Johnson (*7*) has shown that the heterogeneous type can be changed by variations in temperature, and Waterhouse (*17*) observed that the X-type reaction was very common in cultures of *Puccinia triticina* on the standard varieties in the greenhouse at certain periods of the year. All the cultures of the writers were grown on differential varieties for several uredinial generations but usually over a relatively short period of time. Table 2 shows some comparisons of closely related forms that differ only in a few respects, principally by a difference in the reaction of a single variety.

TABLE 2.—*Comparison of several physiologic forms of Puccinia triticina that differ from one another only slightly*

Physiologic form	Number of uredinial generations tested	Type of infection on wheat variety—							
		Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat
3	8	0–1	0–2	2–2+	0–2	2–4	3–4	0–1	4
15	8	0	0	0–1	0	0–1	4	0–1	4
34	7	0	0	0	0–1	1	4	X	4
33	8	0	1	2+	0–1	4	2+	1	4
44	8	0	2	2	0–2	4	X	0–1	4

In the comparison of forms 3, 15, and 34 it will be noted that the main difference between them is in the variable reaction of Loros in the case of form 3 and the indeterminate reaction of Hussar in the case of form 34. The point is still more striking when forms 33 and 44 are compared. In this case Mediterranean exhibits a 2+ reaction to form 33 and an indeterminate reaction to form 44. Only a slight fluctuation in environmental conditions might be necessary to cause such a slight difference, although the reaction of Mediterranean to each form seemed to be rather constant during the period they were under study and the infection type in each given case might have been quite typical for the variety.

Another condition also has been encountered in these experiments that indicates that some physiologic forms, at least, are really groups of forms. In the course of the writers' studies they have frequently purified, and carried for several generations, cultures that could be run down to described forms in the key but really differed constantly from those forms. Four such cases are shown in Table 3 where certain cultures are compared with described physiologic forms.

TABLE 3.—*Comparison of certain physiologic forms of Puccinia triticina with cultures that apparently are closely related*

Form and culture Nos.	Number of trials	Type of infection on wheat variety—							
		Malakof	Carina	Brevit	Webster	Loros	Mediterranean	Hussar	Democrat
Type form 9		4	1-2	1-2	4	4	0-1	1-2+	0-1
J-170	7	3-4	2	2	3-4	3-4	2+	2	2+
Type form 16		0	0	0	0	0	0	2	0
J-186	6	0-1	0-1	1-2	0-1	1-2	2+	2	2+
Type form 31		4	2	1-2	4	4	1-2	3-4	1-2
J-166-1-9-1	8	4	2	2	4	4	0	4	0
Type form 37		3-4	2+	2	0-2	3-4	2+	2	2+
J-586-A-1	7	4	2	2+	0	4	0-1	2	0-1
J-39-1-1-1	7	3-4	2	2	2	4	0-1	2	0-1

While none of the variant types was tested over more than a single greenhouse season, the readings secured on them at various times during that season constantly indicated that they differed slightly from the forms to which they apparently were related. In the case of culture J-170, Mediterranean and Democrat were constantly much less resistant than to form 9, to which the key indicated it belonged. Culture J-186 showed much the same relationship to form 16, although the difference between the two was still more striking. In culture J-166-1-9-1 the situation is reversed, however, and Mediterranean and Democrat have a more resistant reaction than to form 31. It is much the same with regard to the difference between cultures J-586-A-1 and J-39-1-1-1 and form 37. Here, however, there are also slight differences between the three cultures in their behavior on Webster.

Although many physiologic forms have been very constant in their behavior on differential varieties, certain forms have proved to be variable. The variations apparently are of two main types, viz, those caused by changes in environmental conditions and those due to small but inherent differences between components of a group of

allied strains. Those variations due to environment are fluctuating and the differences indicated by them are only apparent. The differences between group components, on the other hand, are constant and real. It seems, therefore, that certain physiologic forms at least can not be considered as basic units or genetic entities, as some investigators have assumed. They apparently are groups of forms that probably could be further divided. Two methods of attaining further separations present themselves; (1) to make finer distinctions on the basis of types of infection, and (2) to increase the number of differential varieties. The latter would seem to be the more desirable of the two methods if further division of physiologic forms of *Puccinia triticina* proves to be necessary. From a purely mycological standpoint there seems to be good reason for describing as many physiologic forms as possible and for making the finest possible divisions. From a practical standpoint, however, there is considerable doubt about the necessity for finer divisions than are possible with the present group of differential varieties. Increases in the number of varieties mean increases in the time, labor, space, and expense required for physiologic-form determinations. It is admitted that many forms probably could be further divided by increasing the number of varieties, but it should be pointed out that plenty of varieties and hybrids have been found to have resistance to the physiologic forms as they now exist. The economic necessity for finer divisions therefore does not seem to be great.

Scheibe (*14*) gives the reactions of 3 cultures of form 13 and 6 collections of form 11 when used to inoculate 11 standard varieties and 17 other varieties of wheat that his experiments had proved also had differential reaction. His data (*14*, *Table 7*) show that, although the cultures are all typically forms 13 and 11 as far as the 11 standard varieties are concerned, the individual collections actually differ when the host range is extended. He therefore raises the question as to whether 11 standard varieties are enough to differentiate sufficiently the possible physiologic forms of *Puccinia triticina*. The writers have frequently encountered varieties of wheat having differential reaction to leaf rust, but for the sake of uniformity and facility these varieties have not been added to the list of differential varieties.

DISTRIBUTION AND PREVALENCE OF PHYSIOLOGIC FORMS OF PUCCINIA TRITICINA IN THE UNITED STATES AND CANADA

The matter of the distribution and prevalence of physiologic forms of pathogenic organisms is one of considerable interest. Mains and Jackson (*10*), prior to 1926, found that forms to which Malakof (C. I. No. 4898) was resistant were more abundant in the eastern and southern parts of the United States, while those forms to which Malakof was susceptible were more prevalent in the Central West. Scheibe (*14*) found that the most aggressive physiologic forms were most abundant in eastern Germany and eastern Europe, while the less aggressive forms were more common to western Germany and western Europe.

In the writers' experiments since 1926 the conclusion of Mains and Jackson that physiologic forms of rust are neither fixed nor limited in their distribution has been amply verified. The forms that have

been isolated during this period in the greenhouse experiments at La Fayette, Ind., and Manhattan, Kans., and the States and Provinces in the United States and Canada in which the rust collections were made are listed as follows:

Form 1.—Washington, Idaho, Montana, Kansas, Georgia.
Form 2.—Colorado, Kansas.
Form 3.—Georgia, Tennessee, North Carolina, Virginia, Ohio, Indiana, Kansas, Oklahoma, Minnesota, North Dakota, Washington, Idaho, Nova Scotia.
Form 5.—Mississippi, Georgia, North Carolina, Virginia, Maryland, Tennessee, New York, Ohio, Indiana, Kansas, Oklahoma, Texas, Montana, Washington.
Form 6.—Georgia, Tennessee, Indiana, Ohio, Texas.
Form 9.—Georgia, North Carolina, Maryland, Texas, Oklahoma, Kansas, Missouri, Nebraska, Iowa, South Dakota, North Dakota, Minnesota, Colorado, Montana, Oregon, Washington, Ontario, Quebec.
Form 10.—Indiana, Missouri, Colorado, Montana.
Form 11.—Washington, Idaho, Oregon, Texas, Kansas.
Form 15.—Iowa, North Dakota.
Form 20.—Kansas, Texas.
Form 27.—Texas.
Form 28.—Georgia, Virginia, Tennessee, Indiana, Wisconsin.
Form 29.—Tennessee, Virginia, Indiana, Ohio, Kansas, Missouri.
Form 30.—Georgia, North Carolina, Virginia, Tennessee, Ohio, Indiana, Illinois, Wisconsin, Oklahoma, Kansas, New York, Ontario, Quebec, Nova Scotia.
Form 31.—Kansas, Ohio, Georgia.
Form 32.—Virginia, Tennessee, Ohio, Wisconsin, North Dakota, Idaho, Oregon, British Columbia.
Form 33.—Georgia, North Carolina, Tennessee, Texas, Kansas, Nebraska, South Dakota, North Dakota.
Form 34.—Georgia, Tennessee, Ohio, Indiana, Washington.
Form 35.—Tennessee, Kansas.
Form 36.—Kansas, Texas.
Form 37.—Kansas, Iowa, North Dakota.
Form 38.—Oklahoma, Kansas.
Form 39.—Kansas.
Form 40.—Kansas, Oklahoma.
Form 41.—Texas, Kansas.
Form 42.—Texas, Oklahoma, Kansas.
Form 43.—Kansas.
Form 44.—North Dakota, Iowa.
Form 45.—Missouri, Kansas.
Form 46.—Kansas.
Form 47.—Oklahoma, Texas, Kansas.
Form 48.—Oklahoma, Kansas.
Form 49.—Oklahoma, Kansas.
Form 50.—Minnesota.
Form 51.—Texas.
Form 52.—Minnesota.
Form 53.—Georgia.

Several of the forms originally described by Mains and Jackson have a very wide distribution. Forms 3, 5, and 9 have been found in nearly all parts of the United States from which rust collections have been received. However, form 9 has not been encountered so frequently in the Ohio Valley and in the Southeastern States as it has in the Mississippi Valley and in the Great Plains. Forms 3 and 5 are more frequently isolated from southeastern and eastern collections than is form 9. Eight of the 12 forms described by Mains and Jackson have been reisolated since the publication of their results in 1926. Form 1, which is very similar to, if not identical with, form 16 of Scheibe, seems principally to be a form of northwestern distribution. It has been encountered once in collections from

Georgia and once in those from Kansas. Form 2 was isolated only infrequently and from a relatively small area in Kansas and Colorado. Forms 6, 10, and 11 also seem to be relatively unimportant, judging from their distribution and prevalence. Of the forms described by Scheibe in Europe, only forms 11, 15, and 20 were encountered in the writers' studies. Form 15 has appeared rather frequently in recent years in collections of leaf rust from North Dakota and Iowa, but form 20 has been encountered only twice, once in collections made in Texas and once in those from Kansas.

Some of the forms described for the first time in this bulletin have been under investigation long enough to indicate a rather wide distribution. Others have been studied a much shorter time and their distribution and prevalence are imperfectly known. Forms 34 to 52, inclusive, have been encountered only in the Mississippi Valley and the eastern Plains States from Texas and Tennessee northward. That should not be considered the full extent of their distribution, however. They were isolated from rust collections made in that area and studied in the greenhouse at Manhattan. Collections made outside of that area during the same years were not studied at Manhattan.

The data suggest that physiologic forms 3, 5, 9, and 30 are the most abundant forms in the United States, but they do not picture the situation for any particular area for any definite period of time. The situation for the Mississippi Valley and the Great Plains area during the seasons of 1928 and 1929 is indicated by the data presented in Table 4.

TABLE 4.—*Distribution of physiologic forms of Puccinia triticina in the Great Plains area as indicated by isolations from field collections made in 1928 and 1929*

Year and State	Collections tested	Collections containing—		Physiologic forms isolated and number of times (shown in brackets) each was encountered
		Mixture of forms	Individual form	
1928	*Number*	*Number*	*Number*	
Kansas	40	23	17	9 [33], 37 [6], 36 [4], 5 [2], 38 [2], 1 [1], 3 [1], 11 [1], 20 [1], 39 [1].
Oklahoma	4	1	3	9 [4], 37 [1].
Texas	5	1	4	9 [3], 11 [1], 27 [1], 36 [1].
Nebraska	1		1	9 [1].
Iowa	2		2	9 [2].
North Dakota	2		2	9 [2].
Total	54	25	29	9 [45], 37 [7], 36 [5], 5 [2], 11 [2], 38 [2], 1 [1], 3 [1], 20 [1], 27 [1], 39 [1].
1929				
Kansas	46	18	28	9 [32], 13 [9], 5 [1], 2 [3], 3 [5], 29 [1], 30 [1], 31 [1], 35 [1], 40 [1], 41 [1], 42 [1].
Oklahoma	10	7	3	9 [6], 13 [2], 5 [1], 3 [1].
Texas	37	25	12	9 [7], 13 [6], 3 [2], 5 [1], 6 [1], 20 [1], 33 [1], 42 [5].
Nebraska	4	2	2	9 [4], 13 [1], 33 [1].
Iowa	1	1	0	9 [1], 15 [1].
Missouri	2	2	0	9 [1], 10 [1], 29 [1].
Colorado	1	1	0	2 [1].
Montana	1	1	0	9 [1], 13 [1].
North Dakota	3	2	1	9 [3], 13 [1], 3 [1], 32 [1], 33 [1].
South Dakota	5	1	4	9 [5], 33 [1].
Total	110	60	50	9 [60], 13 [20], 3 [9], 33 [4], 5 [3], 2 [4], 6 [1], 10 [1], 15 [1], 20 [1], 30 [1], 32 [1], 35 [1], 40 [1], 41 [1], 42 [6], 29 [2], 31 [1].

It must be admitted at the outset that these data are fragmentary, at best, especially as regards the whole leaf-rust population of the area. It is obvious that, even with hundreds of rust collections from evenly distributed points over an area, only a scant representation of the physiologic-form flora is obtained. The collections from which the data in Table 4 were derived were not made at evenly distributed points, nor in equal numbers in the various States. They therefore indicate only general trends in form distribution. They do indicate rather strongly, however, that form 9 is the most prevalent and widely distributed form in the area. This has consistently been the case in studies conducted at Manhattan, Kans., since 1926. Of the 54 collections of rust studied in 1928, slightly more than half were composed of only a single form. In such cases form 9 was the form most frequently encountered. Although somewhat more than half of the cultures studied in 1929 proved to be a mixture of forms, physiologic form 9 was again the dominant form. This is well illustrated in the analysis of the data recorded in 1929. Of the 50 cultures that consisted of a single form, 34 were of physiologic form 9. While 60 of the cultures proved to be a mixture of forms, it was possible to identify the forms composing the mixture in only 34 instances. Of these, 31 were composed of 2 forms; 2 of 3 forms; and only 1 of 4 forms. Of the 31 containing 2 forms, form 9 was one of the constituents in 23 cases. Of the cultures containing 3 and 4 forms each, form 9 was a constituent in each case.

The reason for the dominance of physiologic form 9 in the western Plains area is not definitely known, but it can not be doubted that it is particularly well adapted. In most of the cases where field collections of leaf rust have proved to be mixtures of two or more physiologic forms, form 9 usually has comprised the largest part of the mixtures.

It has been noted consistently that physiologic form 9 is the one that most frequently overwinters in Kansas, Oklahoma, and Texas. Collections made during the late fall, winter, and early spring at points in these States have usually been pure form 9. This point is well illustrated in Table 5 by data on the physiologic-form content of collections of leaf rust made at Manhattan during the seasons of 1927–28 and 1930–31, and at Denton, Tex., in the spring of 1928.

TABLE 5.—*Physiologic forms of Puccinia triticina collected at Manhattan, Kans., and Denton, Tex., during different months of 1927, 1928, 1930, and 1931*

Place	Date of collection	Physiologic forms isolated	Place	Date of collection	Physiologic forms isolated
Manhattan, Kans.	June 11, 1927	9, 3, 11, 37, 29.	Manhattan, Kans.	June 30, 1930	9, 13, 19, 3.
	Nov. 25, 1927	9, 29.		Oct. 23, 1930	9, 19, 13, 15.
	Nov. 30, 1927	9.		Nov. 14, 1930	9, 19.
	Dec. 20, 1927	9.		Dec. 26, 1930	9.
	Jan. 6, 1928	9.		Jan. 5, 1931	9.
	May 15, 1928	9, 13.		Feb. 24, 1931	9.
	June 15, 1928	9, 3, 13, 15.		Mar. 6, 1931	9.
Denton, Tex.	Feb. 13, 1928	9.		Apr. 13, 1931	9.
	Mar. 18, 1928	9.		May 20, 1931	9, 5, 13.
	Apr. 10, 1928	9.			
	May 22, 1928	9, 3, 2, 13.			

These data show that at Manhattan the number of physiologic forms may be numerous in summer and early fall, but that physiologic form 9 is the one most generally encountered in late fall and winter. Although no data are available on forms present at Denton in the fall and winter months of 1927–28, form 9 was the only form present in collections made in the early spring of 1928. At both stations the number of forms did not increase to any appreciable extent until about the time of maximum infection at each station.

Whether the data presented above mean that physiologic form 9 is able to overwinter in greater abundance than other forms in the southern Great Plains can not be said with certainty. It can be stated, however, that in experiments covering the period of 1926 to 1931, inclusive, it has been the form usually encountered late in the fall and early in the spring, as well as the form present in greatest abundance during the spring rust season. It has therefore been considered the dominant form in the southern Plains area. Other forms are found, to be sure, but usually after leaf-rust infection is fairly well advanced, and then in relatively small amounts as compared with form 9.

The situation in the Ohio Valley and in the southeastern United States seems to be much different in that no one form appears to be dominant year after year. It is true that forms 3 and 5 are isolated more frequently than any others over a period of several years, but not with the frequency with which form 9 has been found in the Great Plains. A larger number of forms are isolated in the eastern area in any particular season than in the Great Plains area. The reason for this is not clear. If a susceptible species of the aecial host of *Puccinia triticina* occurred in the Eastern and Southern States, the explanation might be said to lie in the hybridization of forms. Jackson and Mains (*6*), however, failed to find any native leaf-rust-susceptible species of Thalictrum. Scheibe (*14*) states that Eremejeva, in Russia, succeeded in obtaining positive infection in 16 species and varieties of Thalictrum, but that *T. minus* and *T. flavum* showed the most decided susceptibility. He also states that Bondarzew has pointed out that these are the species that occur in Russia and become the most severely rusted. Scheibe then ventures the opinion that here there is good circumstantial evidence of the rôle of certain species of Thalictrum in the genesis of new physiologic forms. It may also explain why he found a larger number of physiologic forms in eastern than in western Europe. In the United States, however, the native species of Thalictrum, as far as they have been tested, are resistant to *P. triticina*, and yet there are often many physiologic forms present in a single season. This is especially true of the eastern part of the United States. It seems, therefore, that some factor or factors other than the presence of the aecial host must be sought to explain the distribution and abundance of physiologic forms of leaf rust of wheat in this country.

GENERAL DISCUSSION

Although only 26 physiologic forms of *Puccinia triticina* new to North America are described in this bulletin, many more probably could have been described if finer divisions had been attempted.

Throughout the studies herein reported evidence indicating that some forms could be subdivided was frequently encountered. This seemingly could have been done on the basis of constant differences in infection types produced by different cultures on the same variety. Although infection types have been constantly recorded in data on physiologic forms of cereal rusts, the separation of forms and the construction of keys have been based almost entirely on reaction classes. There seems little doubt that separations could also be made on the basis of infection types, but such data would be much more difficult to use, and errors due to the effect of environment would be more frequent. There seems to be little need for finer distinctions, but it should be kept in mind that they could be obtained. If such necessity arose, reliable results could be obtained only under carefully controlled conditions that could be duplicated by other investigators.

The occurrence within physiologic forms of strains that differ slightly but constantly from one another is not admitted by all investigators. Some feel that these are merely variations, apparently constant for a time but fluctuating if the form be cultured often enough. In such cases it is assumed that the variation is caused by changes in environment. While the writers have had only a few forms in continuous cultures for more than a year, they have tested many forms as frequently as possible during a greenhouse season. This in itself subjected the cultures to considerable change in environment, since the temperature, humidity, length of day, and quality of light vary rather widely during this period. When certain cultures were found to react constantly and to be slightly different from described forms, it seemed reasonable to regard them as members of group forms.

Further evidence that certain physiologic forms are really groups of forms is encountered when they are tested with a larger number of varieties. The matter of increasing the number of differential varieties, thus making it possible to split some of the physiologic forms into two or more forms, probably merits careful consideration. It remains only to determine whether the need is urgent enough and the return sufficient to compensate for the vastly increased amount of time, labor, space, and expense that would be involved were such a course pursued. It is also well to consider how far such a process is likely to be carried. With the thousands of varieties of wheat there would seem to be many thousands of possibilities, and it is likely that a structure so unwieldy as to be practically useless would result. In the United States one of the most frequent uses of physiologic-form determination is in connection with programs of breeding wheats for resistance. There has been no difficulty in finding varieties with resistance to physiologic forms as they now are known. If these forms actually are composites of several forms it is clear that resistance to them is inherited as a unit. It therefore becomes possible to breed for resistance to several forms by a single operation instead of the several operations that would be required if parental varieties were resistant only to finer divisions of the present physiologic forms. In breeding for resistance to leaf rust in the southern Great Plains the senior writer has constantly obtained the greatest field resistance

in crosses involving resistance to several physiologic forms. Therefore, it would seem reasonable to retain the present differential varieties as basic standards, recognizing that others may be added for special purposes, or when it seems advisable to make finer distinctions than now seem necessary.

SUMMARY

All the data on physiologic forms of *Puccinia triticina* are brought together and a key and a table of infection types for 53 physiologic forms are presented.

Thirty-nine physiologic forms, occurring in North America, are described.

The "unnamed" differential varieties of wheat, C. I. Nos. 3756, 3778, 3779, and 3747, are named Carina, Brevit, Loros, and Similis, respectively.

Similis and Norka have been dropped from the list of differential varieties because of their similarity in rust reaction to Webster and Malakof, respectively. It also is pointed out that Michigan Amber does not belong in the group of differential varieties.

Data are presented showing that certain physiologic forms are variable in their expression, and that some forms apparently are closely related members within integral groups that might be separated by the addition to the list of proper differential varieties of wheat.

Distribution and prevalence of physiologic forms in the United States are, as far as known, independent of the occurrence of species of Thalictrum. Physiologic form 9 has proved to be more prevalent and abundant in the southern Great Plains than other forms. In the eastern half of the United States forms 3 and 5 are more frequently encountered than is form 9.

Some evidence is presented indicating that physiologic form 9 is particularly well adapted to conditions in the Great Plains. It is the form most frequently collected in late fall, winter, and early spring.

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RESPONSE OF SWEET CORN TO VARYING TEMPERATURES FROM TIME OF PLANTING TO CANNING MATURITY

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CONTENTS

	Page
Introduction	1
Sources of data	2
The temperature base line	2
Meteorological data for 1924 and 1927	4
Results with Golden Bantam in 1924	7
Results with Golden Bantam in 1927	10
Air-temperature summations	10
Soil-temperature summations	13
Results with Stowell Evergreen in 1924	15
Results with Stowell Evergreen in 1927	17
Air-temperature summations	17
Soil-temperature summations	19
Discussion of results with Golden Bantam and Stowell Evergreen in 1924 and 1927	21
Temperature summations for different varieties	22
Data from corn grown in Iowa	24
Data from corn grown in Maine	26
Data from corn grown in New York	32
General discussion	33
Summary	37
Literature cited	39

INTRODUCTION

In an earlier paper (*13*) [1] on the relation of seasonal conditions to quality in sweet corn, attention was drawn to the fact that the length of time required for Golden Bantam and Stowell Evergreen varieties to reach canning maturity at the Arlington Experiment Farm, Rosslyn, Va., near Washington, D. C., varied with the date of planting, those plantings made between June 7 and July 28, 1924, having matured in a fairly uniform period of time, whereas those made earlier than June 7 or later than July 28 required progressively longer periods to reach canning maturity as the times of planting were farther and farther removed from these dates. These results suggested to the writers that any particular variety or strain of corn might have a definite quantitative temperature requirement, and that a study of these temperature relations might yield results of value to growers, breeders, and canners of sweet corn.

The question is often raised as to how early or how late sweet corn may be planted with safety in a particular region, and sometimes as to whether corn may be grown at all. Furthermore, the adaptation of strains to the needs of a particular climate and other considerations make it desirable to know as much as possible about the temperature relations of this crop. With this in mind, an analysis was made of the climatological and field data assembled during the progress of experimental work prior to 1927, which proved of such interest that a new series of plantings was made during the season of 1927 to check on previous findings and to provide more carefully collected temperature data.

[1] Italic numbers in parentheses refer to Literature Cited, p. 39.

SOURCES OF DATA

Climatic, field, and analytical data on sweet corn grown at the Arlington Experiment Farm were available for the season of 1922, when 15 different varieties were studied; for 1924, when Golden Bantam and Stowell Evergreen were grown; for 1925, when representatives of the various types, nine in all, were studied; and for 1927, when Golden Bantam and Stowell Evergreen were again grown.

The temperature data for 1922, 1924, and 1925 were taken from the official reports of the United States Weather Bureau at Washington, D. C., the observatory of which was located approximately 1 mile from the experiment plots. During the season of 1927, in addition to the official Weather Bureau data, thermograph records of both air and soil temperatures were kept at a station located in the midst of the corn.

In addition, two sets of data were available from the sweet-corn section of Maine, one for the season of 1925 and the other for that of 1926 from the region adjacent to Auburn. Field data were supplied in part by George Bradley, superintendent of a commercial canning plant at Auburn, and in part were collected in the field by the senior writer. Temperature records were secured at the gatehouse of a water-power plant at Lewiston, just across the Androscoggin River from Auburn.

Samples for chemical analysis and field data from Ames, Iowa, for the seasons of 1925 and 1926 were supplied through the courtesy of A. T. Erwin, of the Iowa Agricultural Experiment Station, and temperature records were secured from the official reports.

Material for this study was likewise supplied through the courtesy of A. H. Olin from field records and temperature readings taken in the neighborhood of a commercial plant at Mount Morris, N. Y., about 36 miles south of Rochester.

THE TEMPERATURE BASE LINE

In attempting to determine the temperature requirements of a crop it is necessary first of all to establish the proper minimum-temperature base line from which temperature values may be calculated. It has been the custom among most students of the temperature relations of plants to use 40° F. (4.44° C.) as the base line, it being considered that below this point physiological processes are practically at a standstill. While this temperature may serve fairly satisfactorily as a base line in the general study of plant geography as affected by climate (*9*, *10*), it seems reasonable to question whether it can be used properly in studying the temperature relations of specific crops, except in those cases where 40° is known to be close to the minimum temperature for the crop under consideration. Peas, for instance, may usually be planted as early in the spring as the ground can be worked, and they succeed best where relatively cool temperatures prevail during the growing season. Corn, on the other hand, can not be planted profitably until the ground is well warmed by the sun, and it succeeds under hot, moist conditions. The differences in the response of these two crops to environmental conditions seem to be due primarily to differences in the level and range of effective temperatures. Obviously, therefore, the base line to be used in the study

of temperature relations of corn should not be the same as that used in the study of peas or other crops having a different temperature minimum.

Lehenbauer (*8*), in the report of his studies on corn seedlings held at constant temperatures, indicated the minimum temperature of corn to be near 12° to 14° C. (53.6° to 57.2° F.). More recently Erwin (*5*) recorded the observation that, other conditions being favorable, sweet-corn seed sprouts promptly when the soil temperature is about 55° F. (12.78° C.), and he made use of this temperature as the base line for effective-temperature summations in his work on pumpkins.

In the present study it was decided to work from different temperature base lines in order to see what summations from these various levels would reveal. The method followed was similar to that used by MacDougal (*12*), the total heat exposures above the various base lines being calculated not from the daily means but from the hourly temperature readings and summated as degree-hours. In brief, the plan here followed consisted in growing the corn under widely varying conditions of temperature, which was made possible by planting at intervals throughout the season in the same field from the same lot of seed. The temperatures above various base lines were then summated as degrees-Fahrenheit hours. The base lines chosen were 40°, 45°, 50°, 55°, and 60° F. That base line whose summations showed the smallest standard deviation from the mean was considered to be the best starting point for studies on the response of the corn to different temperatures. The Fahrenheit scale was used because official Weather Bureau temperatures are presented as Fahrenheit values and field records are usually expressed in the same way.

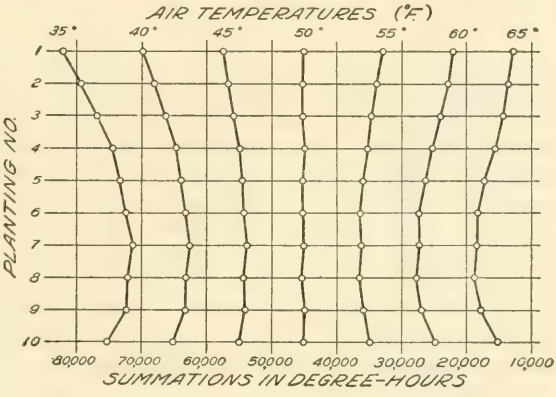

FIGURE 1.—Theoretical air-temperature summations in degree-hours above various base lines for Golden Bantam sweet corn planted at intervals of 10 days at the Arlington Experiment Farm, Rosslyn, Va., beginning April 15 of a normal year. The data are based on the normal mean temperatures for this station, and a summation of 45,000 degree-hours above a proper temperature base line is arbitrarily assumed to be a true summation for the corn used

The principle here involved is made clear by the following hypothetical case. It is assumed that a series of plantings was made at 10-day intervals throughout the season, beginning on April 15 of a year whose daily mean temperature corresponded to the 50-year average for Washington, D. C. The dates of the various plantings are assumed to be as given in Table 1. These dates of canning maturity for the various plantings in the present case were determined by assuming that 50° F. was the proper base line and 45,000 degree-hours was the temperature requirement to bring the corn to canning maturity. The results are presented in Table 1 and illustrated in Figure 1.

TABLE 1.—*Theoretical air-temperature summations for Golden Bantam sweet corn planted at assumed intervals of 10 days, beginning April 15 of a normal year, at the Arlington Experiment Farm, Rosslyn, Va.*

[Based on data of the normal mean temperature for this station. A summation of 45,000 degree-hours above an appropriate base line is arbitrarily assumed to be a true summation for the corn used]

Date of planting	Date of canning maturity	Degree-hours above base line of—						
		35° F.	40° F.	45° F.	50° F.	55° F.	60° F.	65° F.
Apr. 15	July 26	82,104	69,744	57,384	45,024	32,784	21,912	12,936
Apr. 25	July 28	79,368	67,968	56,568	45,168	33,768	22,920	13,512
May 5	July 31	76,800	66,240	55,680	45,120	34,560	24,000	14,376
May 15	Aug. 4	74,448	64,608	54,768	44,928	35,088	25,248	15,528
May 25	Aug. 10	73,248	63,888	54,528	45,168	35,808	26,448	17,088
June 4	Aug. 17	72,216	63,216	54,216	45,216	36,216	27,216	18,216
June 14	Aug. 25	71,232	62,472	53,712	44,962	36,082	27,202	18,322
June 24	Sept. 5	71,976	63,096	54,216	45,336	36,456	27,576	18,696
July 4	Sept. 18	72,288	63,168	54,048	44,928	35,808	26,788	17,668
July 14	Oct. 5	75,192	65,112	55,032	44,952	34,872	24,792	15,096
Mean summation		74,887	64,951	55,015	45,080	35,144	25,410	16,144
Standard deviation		3,567	2,375	1,186	141	1,179	1,971	2,123

It will be noted that the summations above the 50° F. base line have a standard deviation from the mean of only 141 degree-hours, which is less than that of any other base line. An examination of the curves in Figure 1 shows that for the 50° base line the curve is practically a straight line, whereas the summations for base lines both above and below 50° yield curves that deviate more and more from a straight line as higher or lower base lines are used.

It is apparent that this method for determining the proper base line is reliable where temperature alone is the factor involved. In reality the response that sweet corn shows to varying conditions is not quite so simple as this; but that the principle is sound for the study of actual experimental findings will be evident from the data to be presented.

METEOROLOGICAL DATA FOR 1924 AND 1927

In order to facilitate the correlation of seasonal factors with the temperature requirements of the corn, as indicated by the experimental results about to be considered, certain meteorological data for 1924 and 1927 are presented in Figures 2 and 3. Figure 2 is based on the records of the United States Weather Bureau at Washington for the growing season of 1924, and Figure 3 is based on temperature and rainfall records for the season of 1927 made in the cornfield at the Arlington Experiment Farm. Sunshine and day-length data were taken from the official Weather Bureau report for Washington covering the same period.

The season of 1924 was especially favorable for observing the effect of seasonal conditions on the behavior of sweet corn, as already recorded (*13*). During the latter half of April and the first part of May the temperatures were about normal for this region. The remainder of May and the first half of June, however, were abnormally cool, the maximum temperature often falling below the normal mean for the period. From the middle of June to the first of September the temperature did not vary greatly from normal. September was abnormally cool, and October showed the usual fluctuations. The

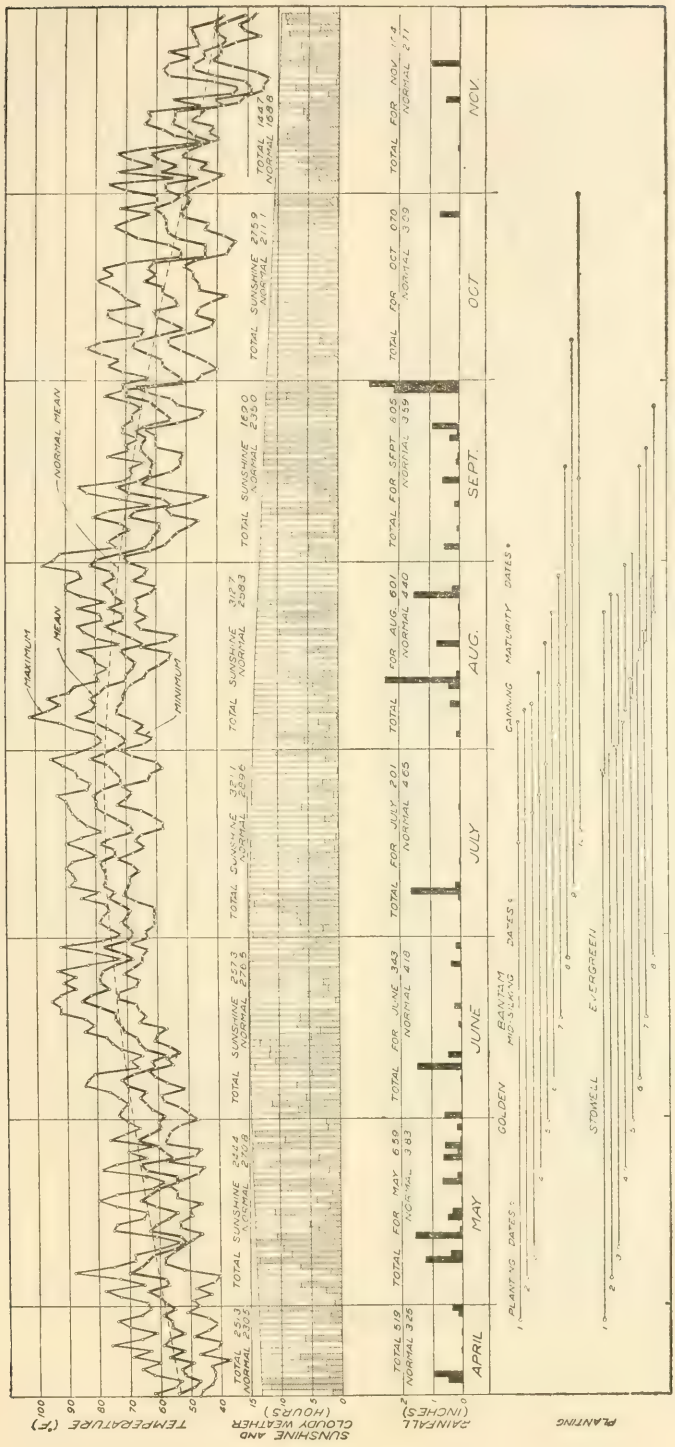

FIGURE 2.—Meteorological data for the season of 1924 at the Arlington Experiment Farm, Rosslyn, Va., and their relation to sweet-corn plantings. (See footnote to Table 5 for explanation of overlapping dates in the case of Stowell Evergreen)

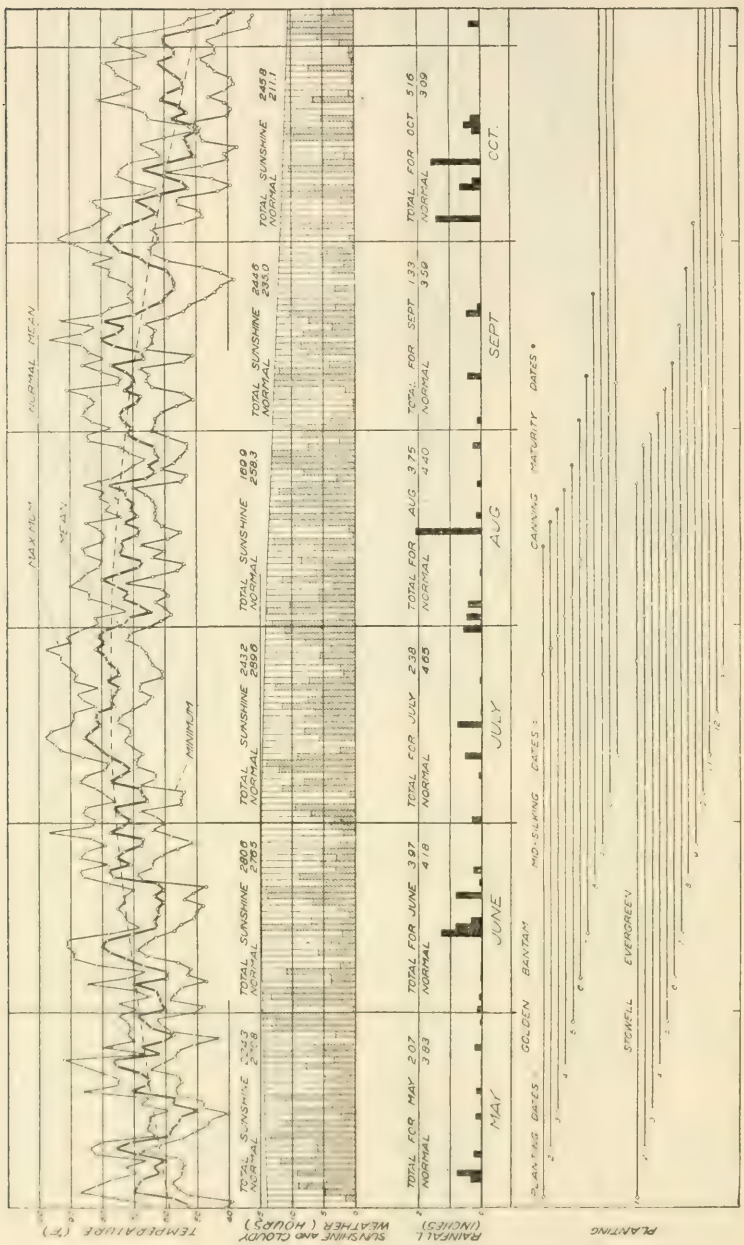

FIGURE 1.—Meteorological data for the season of 1927 at the Arlington Experiment Farm, Rosslyn, Va., and their relation to sweet-corn plantings

rainfall for this period is of particular interest. May was abnormally wet. The rainfall for June was a little below normal but was fairly well distributed. July, with the exception of one abundant rain about the 8th of the month, was practically rainless, and the drought continued well into August. From about the 12th of this month to the end of the active growing season the rainfall was abundant and well distributed. The effect of these conditions, particularly of the rainfall, was very sharply defined in the vegetative response of the corn, as was set forth in some detail in the paper already cited (*13*), and its influence on the temperature-summation data of Stowell Evergreen corn will be seen. (P. 16.)

The season of 1927 was an excellent "corn season." While during the latter part of June and the first week of July the temperature for the most part was somewhat below the 50-year average curve for this period, and the same was true for most of August, this was not sufficient to interfere seriously with the development of the corn. With respect to the rainfall the totals for the various months were somewhat short of normal, but the rain was well distributed, and at no time during the season did the corn suffer for lack of moisture.

RESULTS WITH GOLDEN BANTAM IN 1924

The data of Table 2 show the temperature summations in degree-hours above the base lines 40°, 45°, 50°, 55°, and 60° F. for 10 plantings of Golden Bantam sweet corn grown at the Arlington Experiment Farm during the season of 1924. These summations are based on recorded air temperatures, and two sets of data are given, one for the period from planting to canning maturity and the other from date of planting to the mid-silking date. The former period is given first consideration because it is believed to represent more accurate data. The tagging of ears during the silking period, necessary for their later identification when sampling is done for chemical analysis and canning experiments, often results in the marking of incipient ears that never mature, which in some cases are sufficient in number to affect appreciably the determination of the true mean silking date for a particular plot. These data are included here, however, because they show differences and indicate factors operative in the behavior of corn that need consideration in any physiological study of this crop.

Considering now the data for the periods from planting to canning maturity, it is to be noted that the lengths of these periods varied from 73 days for the seventh planting to 99 days for the first, and 105 days for the tenth planting.

TABLE 2.—*Air-temperature summations for Golden Bantam sweet corn grown at the Arlington Experiment Farm, 1924*

Planting No.	Date of planting	Mid-silking date	Canning maturity date	Degree-hours above base line indicated from planting to canning maturity					Degree-hours above base line indicated from planting to mid-silking				
				40° F.	45° F.	50° F.	55° F.	60° F.	40° F.	45° F.	50° F.	55° F.	60° F.
1	Apr. 28	July 16	Aug. 5	68,228	56,182	44,598	33,254	23,052	51,264	41,622	32,429	23,502	15,890
2	May 5	July 20	Aug. 7	67,240	55,797	44,719	33,815	23,830	51,156	41,857	32,940	24,213	16,386
3	May 10	July 21	Aug. 8	65,279	54,322	43,685	33,210	23,607	49,133	40,320	31,844	23,546	16,101
4	May 23	July 24	Aug. 13	63,961	53,964	44,170	34,332	24,833	46,409	38,796	31,401	23,982	16,881
5	May 31	July 29	Aug. 18	63,241	53,634	44,085	34,536	25,183	46,450	39,207	32,067	24,949	17,948
6	June 7	Aug. 3	Aug. 23	63,127	53,749	44,492	35,067	25,776	46,690	39,687	32,769	25,832	18,864
7	June 17	Aug. 11	Aug. 29	61,801	52,711	44,135	35,177	26,366	48,125	41,388	34,707	27,978	21,260
8	June 27	Aug. 21	Sept. 16	64,131	54,301	44,649	34,865	25,591	46,168	39,471	32,792	26,044	19,411
9	July 9	Sept. 3	Oct. 7	66,033	55,148	44,568	34,105	24,557	47,871	41,051	34,268	27,340	20,600
10	July 18	Sept. 14	Oct. 31	67,191	54,779	43,339	31,876	22,224	46,147	39,080	32,118	25,105	18,467
Mean summation				65,023	54,459	44,244	34,024	24,502	47,941	40,248	32,734	25,249	18,180
Standard deviation				2,202	1,047	454	1,022	1,308	1,981	1,149	1,042	1,546	1,881

It is seen in the 40° F. column (planting to canning maturity) that the summations from the first to the seventh plantings gradually decrease and then progressively increase for the later plantings. In the 45° column the same tendency is shown, but the differences are not so marked, whereas in the 50° column there is a striking agreement in the number of degree-hours required for all plantings. Continuing to the 55° column, it is seen that differences again appear but in the reverse order from those in the 40° and 45° columns, whereas in the 60° column the differences are more marked than in the 55° column. These results may be grasped a little more readily, perhaps, from curves based on these figures as presented in Figure 4.

Figure 4 shows that although the planting dates ranged from April 28 to July 18, and the corresponding range of dates when the corn came to canning maturity was from August 5 to October 31, all plantings used practically the same amount of heat above 50° F., the average for the 10 plantings being 44,244 degree-hours, with a standard deviation of only 454 degree-hours from this average. It would ap-

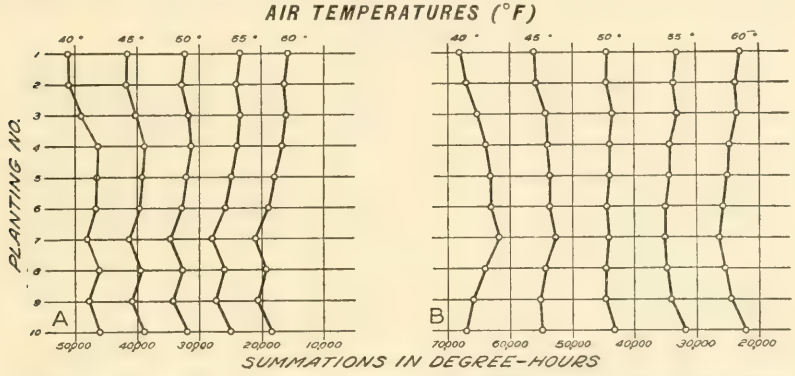

FIGURE 4.—Curves of air-temperature summations in degree-hours above various base lines for the periods, (A) from planting to mid-silking and (B) from planting to canning maturity, for 10 plantings of Golden Bantam sweet corn grown at the Arlington Experiment Farm during the season of 1924

pear from this that 50° air temperature for the Golden Bantam corn grown at the Arlington Experiment Farm during 1924 was the proper minimum-temperature base line from which to calculate effective temperature summations. It is to be noted that these practical findings agree in striking manner with the theoretical data presented in Table 1 and illustrated in Figure 1.

Turning now to the data and curves for the period from planting to mid-silking, two features deserve notice; one, the irregularity of the results, and the other, the indication that a different minimum-temperature base line should be used in the summations for this period. That irregularities may be expected in data for this period has already been mentioned. It seems evident that, as will be shown later, drought may have influenced these results, for moisture conditions for some of these plantings were very severe. The point worthy of particular note is the fact that 45° F. instead of 50° seems to be the proper base line to be applied in summations for these periods. The average summation of temperature above the base line of 45° is 40,248 degree-hours, with a standard deviation of 1,149 degree-hours.

It would appear that the response of the corn to environmental temperature conditions for the period from mid-silking to canning maturity differed from that for the period from planting to mid-silking. How much of this difference is due to error of the method can not be stated, but that this is not an isolated case will be indicated by the figures for another year as well as for another variety of corn.

RESULTS WITH GOLDEN BANTAM IN 1927

AIR-TEMPERATURE SUMMATIONS

Before presenting the data on Golden Bantam for 1927 it should be explained that during the season some of the plantings of this variety particularly suffered very heavily in the field from injury to the ears by blackbirds and ear worms. This injury interfered not only with the collection of adequate samples in those cases but also with the accurate determination of the dates when the plots as entities came to canning maturity. The data for the period from planting to canning maturity may therefore be subject to some error, and the

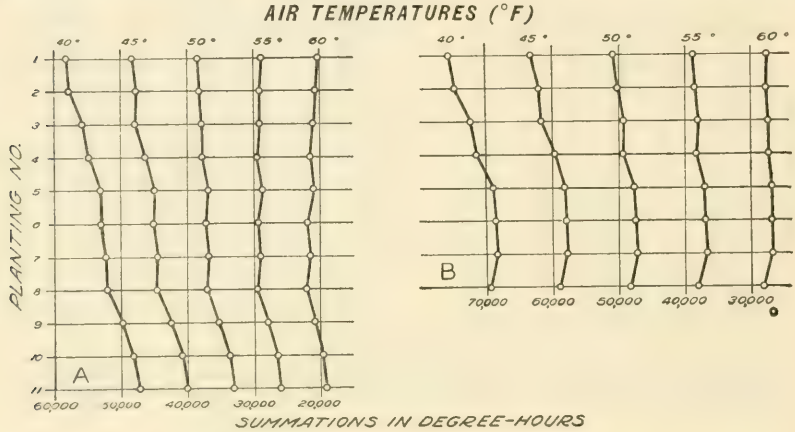

FIGURE 5.—Curves of air-temperature summations in degree-hours above various base lines for 11 plantings of Golden Bantam sweet corn grown at the Arlington Experiment Farm during 1927, (A) for the period from planting to mid-silking and (B) for 8 plantings of the same series for the period from planting to canning maturity. The last three plantings of this series did not reach canning maturity

reader is cautioned against placing too much reliance on this part of the data. On the other hand, records for the period from planting to mid-silking are as accurate as it was possible to make them. The data are presented in Table 3 and Figure 5.

Considering first the figures for the period from planting to canning maturity, it is noted that the planting dates ranged from May 2 to July 11 and that the length of time from planting to canning maturity varied from a known period of 103 days in the first to a close estimate of 88 days in the fifth, sixth, and seventh plantings. Here similar tendencies with respect to variation in the summations are shown, as in the data for 1924, with the difference that 60° F. instead of 50° is indicated as the proper minimum-temperature base line for the period from planting to canning maturity. The average degree-hour summation above 60° for the first eight plantings is 27,413, with a standard deviation of only 437 degree-hours.

TABLE 3.—*Air-temperature summations for Golden Bantam sweet corn grown at the Arlington Experiment Farm, 1927*

Planting No.	Date of planting	Mid-silking date	Canning maturity date	Degree-hours above base line indicated from planting to canning maturity					Degree-hours above base line indicated from planting to mid-silking				
				40° F.	45° F.	50° F.	55° F.	60° F.	40° F.	45° F.	50° F.	55° F.	60° F.
1	May 2	July 24	Aug. 13	75,694	63,264	50,890	38,808	27,735	58,179	48,269	38,415	28,852	20,255
2	May 10	July 28	Aug. 17	74,765	62,123	50,199	38,550	27,723	57,775	47,653	38,249	29,119	20,747
3	May 16	July 30	Aug. 19	72,259	61,651	49,308	38,053	27,467	55,858	47,770	37,947	29,211	21,080
4	May 23	Aug. 2	Aug. 22	71,553	59,696	49,263	38,267	27,445	54,788	46,272	37,778	29,421	21,515
5	May 30	Aug. 5	Aug. 26	69,016	58,336	47,666	37,110	27,035	53,121	44,961	36,811	28,765	21,091
6	June 6	Aug. 11	Sept. 2	68,580	58,020	47,465	36,999	27,047	53,043	45,123	37,208	29,366	21,869
7	June 13	Aug. 17	Sept. 9	68,328	57,768	47,210	36,736	26,772	52,290	44,490	36,692	28,952	21,512
8	June 22	Aug. 23	Sept. 22	69,334	58,893	48,454	38,065	28,081	52,132	44,572	37,012	29,461	22,068
9	June 27	Aug. 27							49,812	42,492	35,172	28,033	20,754
10	July 5	Sept. 3							48,091	40,890	33,691	26,509	19,574
11	July 11	Sept. 8							47,224	40,144	33,064	26,011	19,232
Mean summation (8 plantings)				71,191	59,969	48,807	37,823	27,413	54,648	46,139	37,514	29,143	21,267
Standard deviation (8 plantings)				2,866	2,099	1,337	772	437	2,406	1,468	668	266	596
Mean summation (11 plantings)									52,938	44,785	36,549	28,518	20,882
Standard deviation (11 plantings)									3,435	2,589	1,726	1,135	859

In comparing the figures and curves for the period from planting to mid-silking with the theoretical data of Table 1 and Figure 1, it is noted that, taken in their entirety, the responses of the various plantings to temperature conditions did not conform to the theoretical, in that while the first eight plantings behaved "normally" the results of the last three plantings were out of line with expectations. For this reason it was thought best to analyze the data on two bases, one including the first eight plantings and the other including the entire group. The explanation of the "abnormal" trends in the curves for the last three plantings will be discussed later.

If the data of the first eight plantings are studied it will be found that, as in 1924, the greatest uniformity in the summations fell in the column 5° lower than that for the period from planting to canning maturity, that is, in the 55° F. column. The average summation for the first eight plantings here was 29,143 degree-hours, with a standard deviation of only 266 degree-hours.

Comparing these results with those for the season of 1924, it is apparent that this corn grown at the Arlington farm during 1927 developed within a different temperature range from that grown in 1924, since the base line in 1927 was 10 degrees higher than that in 1924. The reason for this difference can not be assigned with certainty. The seed in both cases was purchased from the same midwestern seedsman and to all appearances was of excellent quality with respect not only to uniformity in size, color, and weight of the seed itself but also to the vigor and unformity of the plants derived therefrom. To what extent seasonal factors may have affected the results for the two years can not be stated definitely; but since Stowell Evergreen grown in the same fields under identical conditions did not show this difference in behavior it is probable that the explanation is to be sought in some other factor. It is believed, from the results obtained from various strains of Golden Bantam, which will be presented later, that this difference in behavior in the two years was due to strain differences in the seed.

One feature of the results for the period from planting to mid-silking is worthy of special note, namely, the progressive lessening of the summations in all temperature columns for the last three plantings, as seen in the second set of figures of Table 3 and the curves of Figure 5. Similar results were obtained with Stowell Evergreen, as will be shown presently. It will be noted that the ninth, tenth, and eleventh plots of corn were planted on June 27, July 5, and July 11, respectively, a season when soil temperatures were approaching the highest level of the season. The effect of the increase of soil temperatures would be to speed up the germination of the seed and thus cut down progressively the length of the growing period. It is possible that length of day and perhaps other factors also contributed to this result. If the data of the series from planting to mid-silking are considered as a whole, it is seen that the standard deviation is smallest for the 60° F. base line instead of for the 55° base line, as is the case when the first eight plantings only are considered. This result, as will be seen from the curves of Figure 3, is due to the "abnormal" trends in the curves for the last three plantings.

SOIL-TEMPERATURE SUMMATIONS

In the region where this work was done, mean soil temperatures in the early spring lag considerably behind the mean air temperatures. As the season advances the curve of the soil temperatures gradually approaches that of the air temperatures, until in July it reaches and crosses it. For a considerable period thereafter the mean soil temperatures remain above those of the air.

In planning the work for 1927 it was thought that summations based on soil-temperature data might be of value in the present study, as much of the activity of the corn plant is carried on underground, particularly during the early growing period. Soil temperatures throughout the entire season were therefore recorded, and the summations for Golden Bantam corn based on these records are presented in Table 4 and illustrated in Figure 6.

Two observations are to be made from these data when compared with those for air temperature—(1) that the minimum-temperature

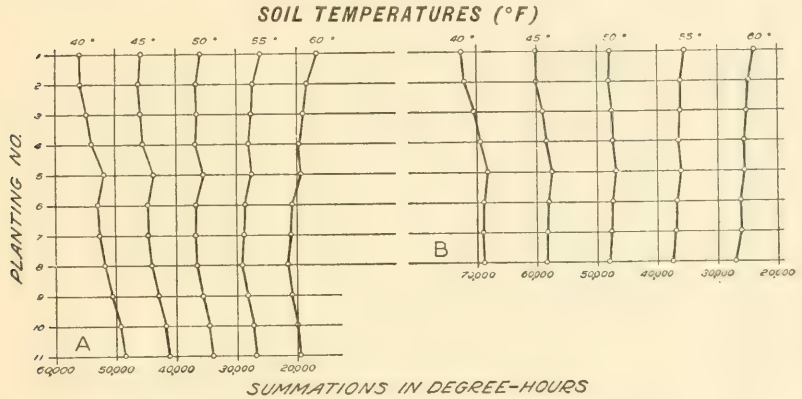

FIGURE 6.—Curves of soil-temperature summations in degree-hours above various base lines for 11 plantings of Golden Bantam sweet corn grown at the Arlington Experiment Farm during 1927, (A) for the period from planting to mid-silking and (B) for 8 plantings of the same series for the period from planting to canning maturity. The last three plantings of this series did not reach canning maturity

base line is lower than in the air-temperature data; and (2) that the data of both periods, that is, from planting to canning maturity and from planting to mid-silking, indicate the same base-line temperature, 50° F. The average summation above this temperature for the period from planting to canning maturity is 47,532 degree-hours, with a standard deviation of 406 degree-hours. For the period from planting to mid-silking the average summation for the first eight plantings is 36,381 degree-hours, with a standard deviation of 454 degree-hours.

The difference in air and soil temperatures during the growing season explains, in part at least, the differences in indicated base lines as determined from the air-temperature and soil-temperature data. It is plain that, since in the early part of the season the response of the corn is influenced by soil temperatures more than by air temperatures, the air-temperature base lines as here determined do not represent the true physiological minimum temperature for corn, which

TABLE 4.—*Soil-temperature summations for Golden Bantam sweet corn grown at the Arlington Experiment Farm, 1927*

Planting No.	Date of planting	Mid-silking date	Canning maturity date	Degree-hours above base line indicated from planting to canning maturity					Degree-hours above base line indicated from planting to mid-silking				
				40° F.	45° F.	50° F.	55° F.	60° F.	40° F.	45° F.	50° F.	55° F.	60° F.
1	May 2	July 24	Aug. 13	72,627	60,147	47,812	35,407	23,968	55,794	45,714	35,779	25,774	16,735
2	May 10	July 28	Aug. 17	72,011	60,011	48,011	36,143	24,874	55,838	46,238	36,638	27,170	18,301
3	May 16	July 30	Aug. 19	70,537	59,017	47,497	36,076	25,051	54,775	45,655	36,535	27,514	18,889
4	May 23	Aug. 2	Aug. 22	69,426	58,386	47,346	36,308	25,457	53,938	45,298	36,658	28,020	19,569
5	May 30	Aug. 5	Aug. 26	68,122	57,442	46,762	36,082	25,529	51,854	43,694	35,534	27,374	19,341
6	June 6	Aug. 11	Sept. 2	68,876	58,026	47,345	36,665	26,075	52,761	44,721	36,681	28,641	20,683
7	June 13	Aug. 17	Sept. 9	68,881	58,204	47,523	36,843	26,132	52,493	44,573	36,653	28,733	20,874
8	June 22	Aug. 23	Sept. 22	68,839	58,400	47,959	37,519	26,987	51,692	44,132	36,572	29,012	21,452
9	June 27	Aug. 27							50,424	42,984	35,544	28,104	20,664
10	July 5	Sept. 3							49,153	41,834	34,513	27,193	19,881
11	July 11	Sept. 8							48,409	41,212	34,011	26,811	19,519
Mean summation (8 plantings)				69,915	58,704	47,532	36,380	25,509	53,643	45,003	36,381	27,780	19,480
Standard deviation (8 plantings)				1,642	955	406	630	894	1,686	868	454	1,059	1,539
Mean summation (11 plantings)									52,466	44,187	35,920	27,668	19,628
Standard deviation (11 plantings)									2,501	1,626	944	954	1,338

must be below that given, and would be below the air-temperature base line in any region or season where the soil-temperature gradient is normally below that of the air. Since the corn plant carries on physiological activities both in the soil and in the air, and since the soil and air temperature gradients vary continuously with respect to each other, it is impossible at the present stage of knowledge to evaluate these data in such a way as to give a true and accurate value for the actual physiological minimum temperature. It is apparent, however, that this value would lie within the limits given in the soil and air-temperature data unless there were other interfering factors.

In the summations based on soil temperatures, as pointed out in the discussion of those based on air temperatures, there is observed a progressive lessening of the summations of the last three plantings.

RESULTS WITH STOWELL EVERGREEN IN 1924

The differences in the seasonal conditions for 1924 and 1927 are reflected in the summation data for Stowell Evergreen. Table 5 and Figure 7 present the results obtained for 1924.

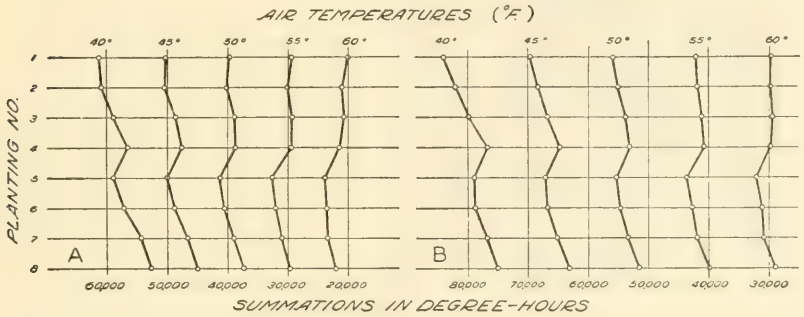

FIGURE 7.—Curves of air-temperature summations in degree-hours above various base lines for eight plantings of Stowell Evergreen sweet corn grown at the Arlington Experiment Farm during 1924, (A) for the period from planting to mid-silking and (B) from planting to canning maturity

It is noted at once that the figures and the curves based upon them show striking irregularity, the first four plantings exhibiting the usual gradations, while the remaining four differ considerably in the degree-hours of temperature making up the totals for these plantings. The greatest uniformity is found in the figures of the 60° F. column for the period from planting to canning maturity, the average summation for the eight plantings being 30,131 degree-hours, with a standard deviation of 1,064 degree-hours. The aberrant results obtained for the last four plantings find their explanation in the effect of drought conditions on the corn. Field records show that the corn of the fifth planting came to silking during the most trying part of the summer, these plants requiring three weeks to complete approximately the silking process, whereas earlier plots of corn derived from the same lot of seed required but two weeks to accomplish the same result. The sixth and seventh plantings required 18 and 17 days, respectively. The striking effects of the drought on the vegetative activities of the corn, such as stunting of growth, decreasing the yield, etc., were particularly noticeable in the plantings of Stowell Evergreen. Attention was drawn to this in the report previously mentioned (*13, p. 1048–1049*).

TABLE 5.—*Air-temperature summations for Stowell Evergreen sweet corn grown at the Arlington Experiment Farm, 1924*

Planting No.	Date of planting	Mid-silking date	Period from mid-silking to canning maturity [1]	Degree-hours above base line indicated from planting to canning maturity					Degree-hours above base line indicated from planting to mid-silking				
				40° F.	45° F.	50° F.	55° F.	60° F.	40° F.	45° F.	50° F.	55° F.	60° F.
1	Apr. 28	July 28	July 27 to Aug. 23	84,085	69,728	55,846	42,093	29,630	61,351	50,259	39,626	29,261	20,019
2	May 5	July 31	Aug. 1 to 26	82,127	68,426	55,117	41,865	29,677	60,997	50,388	40,141	30,096	20,951
3	May 10	Aug. 1	do	79,998	66,783	53,915	41,092	29,286	58,868	48,745	38,939	29,323	20,560
4	May 23	Aug. 5	Aug. 7 to 31	76,888	64,853	53,087	40,842	29,680	56,571	47,524	38,698	29,522	21,283
5	May 31	Aug. 12	Aug. 9 to Sept. 2	78,961	67,106	55,386	43,662	31,975	58,868	50,001	41,221	32,566	23,802
6	June 7	Aug. 15	Aug. 17 to Sept. 16	78,849	66,699	54,749	42,728	31,138	57,215	48,778	40,431	32,033	23,641
7	June 17	Aug. 20	Aug. 18 to Sept. 19	76,913	65,143	53,541	41,900	30,821	54,430	46,633	38,864	31,046	23,315
8	June 27	Aug. 29	Aug. 23 to Sept. 26	75,071	63,205	51,535	39,857	28,840	52,663	45,008	37,427	29,659	22,066
Mean summation				79,111	66,493	54,147	41,755	30,131	57,620	48,417	39,418	30,438	21,955
Standard deviation				2,947	2,071	1,417	1,171	1,064	3,034	1,913	1,186	1,289	1,476

[1] In order to determine the temperature summations for the period from mid-silking to canning maturity in this series it was necessary to make use of the data from chemical analyses along with the field records to establish the exact periods to be summated.

The figures and curves for the planting to mid-silking period show similar irregularities. The minimum-temperature base line is not so readily determined as in other series, but it is apparent that it lies close to 50° F., the average summation for this column being 39,418 degree-hours, with a standard deviation of 1,186 degree-hours. Here again is illustrated the lower effective temperature range of the corn for the planting to mid-silking period as observed in the case of the Golden Bantam variety.

RESULTS WITH STOWELL EVERGREEN IN 1927

AIR-TEMPERATURE SUMMATIONS

In Table 6 are given the air-temperature summations above various base lines for Stowell Evergreen grown at the Arlington Experiment Farm during 1927. Two sets of data are again given, one for the period from planting to canning maturity and the other for the period

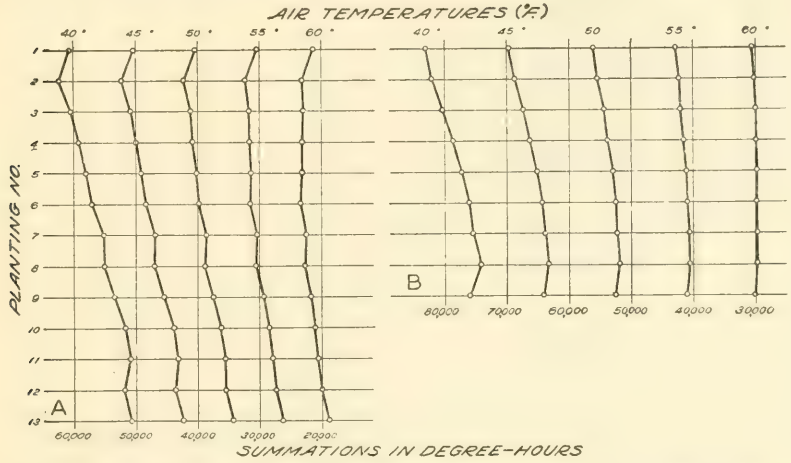

FIGURE 8.—Curves of air-temperature summations in degree-hours above various base lines for 13 plantings of Stowell Evergreen sweet corn grown at the Arlington Experiment Farm during 1927, (A) for the period from planting to mid-silking and (B) for nine plantings of the same series for the period from planting to canning maturity. The last four plantings of this series did not reach canning maturity

from planting to mid-silking, as in earlier tables. Curves based on these results are shown in Figure 8.

Considering the first set, the summations in the columns for the 40°, 45°, 50°, and 55° F. base-line temperatures, the trends from higher to lower summations with successive plantings are again observed, whereas in the 60° column the summations are strikingly uniform for all plantings. The average summation for the nine plantings is 29,924 degree-hours, with a standard deviation of only 250 degree-hours from this average. It would appear from this that 60° air temperature should be considered the minimum-temperature base line for these plantings. This is in agreement with the findings of 1924 for this variety.

TABLE 6.—*Air-temperature summations for Stowell Evergreen sweet corn grown at the Arlington Experiment Farm, 1927*

Planting No.	Date of planting	Mid-silking date	Canning maturity date	Degree-hours above base line indicated from planting to canning maturity					Degree-hours above base line indicated from planting to mid-silking				
				40° F.	45° F.	50° F.	55° F.	60° F.	40° F.	45° F.	50° F.	55° F.	60° F.
1	May 2	July 26	Aug. 23	83,235	69,605	56,031	42,749	30,497	60,792	50,522	40,308	30,385	21,428
2	May 10	Aug. 2	Aug. 29	82,106	68,682	55,318	42,241	30,086	62,552	52 378	42,254	32,404	23,312
3	May 16	Aug. 4	Aug. 31	80,270	67,336	54,439	41,958	29,898	60,545	50,851	41,194	31,738	22,887
4	May 25	Aug. 7	Sept. 3	78,738	66,262	53,808	41,508	29,861	59,238	50,002	40,788	31,711	23,085
5	May 30	Aug. 11	Sept. 7	77,237	65,117	53,007	41,028	29,695	57,964	49,084	40,214	31,449	23,099
6	June 6	Aug. 15	Sept. 11	76,050	64,290	52,535	40,880	29,826	56,964	48,444	39,929	31,488	23,418
7	June 13	Aug. 20	Sept. 17	75,536	63,895	52,258	40,720	29,729	55,172	46,892	38,614	30,394	22,474
8	June 22	Aug. 28	Sept. 26	74,152	63,267	51,784	40,482	29,729	55,080	46,920	38,760	30,618	22,709
9	June 27	Sept. 1	Oct. 3	76,027	64,195	52,474	40,957	29,995	53,540	45,500	37,460	29,445	21,729
10	July 5	Sept. 7							51,827	44,027	36,227	28,455	20,992
11	July 11	Sept. 12							50,903	43,223	35,543	27,890	20,524
12	July 18	Sept. 23							51,815	43,656	35,540	27,545	19,951
13	July 25	Oct. 1							50,650	42,415	34,297	26,372	18,915
Mean summation (9 plantings)				78,150	65,850	53,517	41,391	29,924	57,983	48,955	39,947	31,070	22,682
Standard deviation (9 plantings)				3,140	2,255	1,474	771	250	3,041	2,221	1,464	916	692
Mean summation (13 plantings)									55,926	47,224	38,548	29,992	21,888
Standard deviation (13 plantings)									4,070	3,272	2,521	1,894	1,434

In the figures for the planting to mid-silking period, irregularities are noted. With the exception of the figures for the first planting, which clearly reflect the abnormally high temperatures prevailing at and for some time after the date of planting of this plot (fig. 8), the summations for the first nine plantings are fairly uniform in the 60° F. column, the average for these plantings being 22,682 degree-hours, with a standard deviation of 692 degree-hours. However, there are only slightly greater irregularities in the 55° column, the average for the first nine plantings being 31,070 degree-hours, with a standard deviation of 916 degree-hours.

It is to be noted that the irregularity showing in the figures for the first planting does not appear in the summation for the period from planting to canning maturity, this lower summation than the average

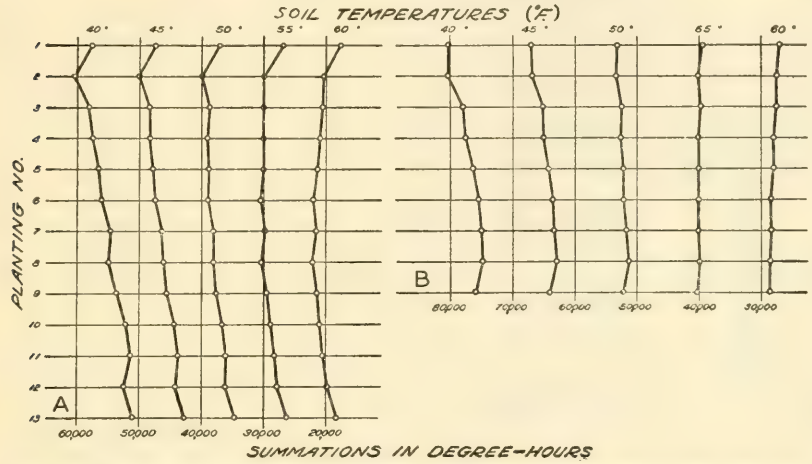

FIGURE 9.—Curves of soil-temperature summations in degree-hours above various base lines for 13 plantings of Stowell Evergreen sweet corn grown at the Arlington Experiment Farm during 1927, (A) for the period from planting to mid-silking and (B) for nine plantings of the same series for the period from planting to canning maturity. The last four plantings of this series did not reach canning maturity

of the eight plantings being offset by the greater temperature requirement from mid-silking to canning maturity.

Beyond the eighth planting is again observed the gradual lessening in the total amount of heat required by the corn, which was noted in the corresponding results with Golden Bantam already shown.

The indicated minimum-temperature base line here is 60° F. instead of 55° as in the case of the 1924 Stowell Evergreen, the proper base line for both the planting to canning maturity and the planting to mid-silking periods being apparently the same. Whether this indicates strain differences in seed may be questioned. The results obtained from summations based on soil temperatures seem to indicate no difference. The results for both periods here indicate a base line of 55°, which corresponds exactly with the results obtained with Stowell Evergreen in 1924.

SOIL-TEMPERATURE SUMMATIONS

Soil-temperature summations above the various base lines for Stowell Evergreen in 1927 are presented in Table 7 and Figure 9.

TABLE 7.—*Soil-temperature summations for Stowell Evergreen sweet corn grown at the Arlington Experiment Farm, 1927*

Planting No.	Date of planting	Mid-silking date	Canning maturity date	Degree-hours above base line indicated from planting to canning maturity					Degree-hours above base line indicated from planting to mid-silking				
				40° F.	45° F.	50° F.	55° F.	60° F.	40° F.	45° F.	50° F.	55° F.	60° F.
1	May 2	July 26	Aug. 23	80,360	66,680	53,145	39,540	26,901	57,616	47,296	37,121	26,876	17,597
2	May 10	Aug. 2	Aug. 29	80,283	66,843	53,403	40,095	27,391	60,266	50,066	39,866	29,798	20,329
3	May 16	Aug. 4	Aug. 31	78,040	65,200	52,360	39,940	27,483	57,987	48,387	38,787	29,607	20,382
4	May 23	Aug. 7	Sept. 3	77,605	65,125	52,645	40,167	27,884	57,641	48,401	39,161	29,923	20,872
5	May 30	Aug. 11	Sept. 7	76,443	64,326	52,205	40,085	28,000	56,693	47,813	38,933	30,053	21,500
6	June 6	Aug. 15	Sept. 11	75,493	63,635	52,075	40,215	28,445	56,063	47,443	39,023	30,503	22,065
7	June 13	Aug. 20	Sept. 17	75,014	63,376	51,736	40,096	28,425	54,688	46,408	38,128	29,848	21,629
8	June 22	Aug. 28	Sept. 26	74,896	62,831	51,311	40,009	28,514	54,775	46,188	38,148	30,295	22,139
9	June 27	Sept. 1	Oct. 3	76,026	64,148	52,268	40,419	28,707	53,636	45,596	37,556	29,516	21,484
10	July 5	Sept. 7							52,163	44,363	36,565	28,765	20,873
11	July 11	Sept. 12							51,359	43,680	35,999	28,319	20,547
12	July 18	Sept. 23							52,406	44,247	36,086	27,928	19,771
13	July 25	Oct. 1							51,168	42,892	34,611	26,362	18,250
Mean summation (9 plantings)				77,129	64,685	52,350	40,063	27,972	56,596	47,511	38,525	29,602	20,866
Standard deviation (9 plantings)				2,099	1,403	650	238	611	2,047	1,363	858	1,056	1,388
Mean summation (13 plantings)									55,112	46,368	37,691	29,061	20,557
Standard deviation (13 plantings)									2,872	2,130	1,536	1,322	1,363

Considering the data for the period from planting to canning maturity, it is noted that the curves of the soil-temperature summations do not differ materially from those of the air temperatures. The appropriate base line indicated here is 55° F., 5 degrees below that of the indicated air-temperature base line—such a difference as has been noted in previously considered data. The average summation for the nine plantings in the 55° column is 40,063 degree-hours, with a standard deviation of only 238 degree-hours.

In the case of the data for the period from planting to mid-silking for the first nine plantings, the smallest standard deviation is found in the 50° F. column, where the mean summation is seen to be 38,525 degree-hours, with a standard deviation of 858 degree-hours. This is a lower base line than would be expected, considering the data that have already been presented, and the standard deviation is likewise unduly great. Inspection of the curves of Figure 9, however, reveals the explanation for this and indicates that in this case, as in the curves for the period from planting to canning maturity, 55° is the indicated base line, the aberrant results in the case of the first planting of the series being responsible for the higher standard deviation in the 55° column than in the 50° column. The reason for this abnormally low summation for the first planting has already been discussed. The mean summation for the 55° column is 29,602 degree-hours and the calculated standard deviation 1,056 degree-hours.

DISCUSSION OF RESULTS WITH GOLDEN BANTAM AND STOWELL EVERGREEN IN 1924 AND 1927

On the basis of the experimental findings set forth, what may be concluded as to the minimum-temperature base line for sweet corn? It must be recognized, of course, that temperature is but one of the factors influencing the behavior of corn in the field, and before an absolute evaluation can be made of the influence of one factor the others must be taken into consideration. The amount and distribution of the rainfall has a tremendous influence on crop activities, as every farmer and investigator knows. The amount of sunshine that the corn receives has an effect on photosynthesis in the plant, and the factor of variable day length must be considered in this connection also. That varieties differ in their time requirements for growth and maturity is well known. Obviously, therefore, the temperature needs of all can not be the same, and it is clear that absolutely uniform results are not to be expected from any set of experiments where these variable factors are not under complete control.

In the experiments here recorded practical field conditions prevailed. The different plots of corn for both seasons were grown, however, in different portions of the same field with no essential difference in cultural practices except that the Golden Bantam was thinned to a distance of 8 to 10 inches in the row, and the Stowell Evergreen plants were spaced 12 to 14 inches. The seed for both seasons was obtained from the same seedsman but, in all probability, was from different seasons' plants for the different years, as was indicated by the difference in the vegetative character of the plants for the two years. The periods covered were essentially the same for both seasons, so that the day-length factor was practically constant for one series of plantings as compared with the other series. Within each series the day-length factor, of course, was variable. No measure of the light inten-

sity as influencing photosynthetic activity was available except the inadequate record of the hours of sunshine and cloudiness, which at present can not be evaluated accurately for this purpose.

If a series of plots of corn planted at intervals of a week or 10 days could be grown with all conditions uniform except those of temperature and time, in view of the results reported by Livingston and Livingston (*10*), and as clearly illustrated by the hypothetical case earlier considered, it would be expected that temperature summations above a proper minimum base line would be uniform for all plots, and that summations of temperature above or below this proper base line would be lacking in uniformity, for the reason that if too low a base line were chosen the summations would include an excess of temperature above that required by the corn, whereas if the base line chosen were too high the summations would not be a sufficient measure of the temperature needs of the crop. It is believed, therefore, that the striking uniformity in the summations of temperature above certain base lines found in the present study indicates rather conclusively the proper base lines for these different corns.

On these grounds it seems reasonable to assume that for the Golden Bantam variety grown at the Arlington Experiment Farm during 1924 the minimum air-temperature base line was 50° F. for the period from planting to canning maturity, considered as a whole, with a slightly lower minimum for growth up to the flowering stage and a slightly higher minimum for the storage of the starch and other carbohydrates in the grain until canning maturity at least was reached. The 1927 Golden Bantam responded to environmental conditions in a similar manner, but its minimum air temperature for the period from planting to canning maturity for some reason was 10 degrees higher. The minimum soil temperature for this corn was 50°, and the base line was the same for the two periods considered.

The minimum air-temperature base line for Stowell Evergreen for both 1924 and 1927 was 60° F., with the same sort of variation with the age of the corn as shown by the Golden Bantam. The minimum soil temperature for the 1927 Stowell Evergreen was 55°.

The minimum-temperature base line for sweet corn, therefore, has been found to differ, not only with different varieties but also with different strains of the same variety, and the amount of heat required to bring the corn to canning maturity has been found to differ likewise with variety and strain. The effectiveness of the temperature in bringing the corn to canning maturity has also been found to be influenced by drought, by soil temperature at planting time, and probably also by day length, light intensity, and possibly other factors.

It seems reasonable to conclude also that since certain varieties and strains of sweet corn have lower minimum temperature requirements than other varieties and strains, such low minimum temperature corns might be planted earlier in the season than those having a higher minimum, and thus be better suited for cultivation in regions having short growing seasons.

TEMPERATURE SUMMATIONS FOR DIFFERENT VARIETIES

It may be of interest to consider the temperature requirements of corns grown at the Arlington farm and at other places during these and other seasons. In Table 8 are shown the summations for dif-

ferent varieties of sweet corn grown at the Arlington farm during 1922, 1925, and 1926.

TABLE 8.—*Air-temperature summations for different varieties of sweet corn grown at the Arlington Experiment Farm, 1922, 1925, and 1926*

[Based on data for the period from planting to canning maturity]

Year and variety	Degree-hours above base line of—				
	40° F.	45° F.	50° F.	55° F.	60° F.
1922					
Golden Bantam	58,923	50,187	41,452	32,746	24,179
Howling Mob	62,067	52,861	43,646	34,460	25,413
Dreer Golden Giant	60,853	51,997	43,152	34,321	25,596
Charlevoix	67,818	57,772	47,717	37,691	27,804
Morse Golden Cream	63,950	54,624	45,289	35,978	26,773
Kelly Hybrid	65,821	56,135	46,440	36,769	27,209
Hickox Improved	63,905	54,579	45,244	35,933	26,728
Potter Excelsior	67,261	57,455	47,640	37,849	28,169
Vaughn Bantam Evergreen	69,321	59,155	48,980	38,829	28,789
Mammoth Sugar	69,044	58,878	48,703	38,552	28,512
Old Colony	71,934	61,408	50,873	40,362	29,962
Narrow-Grained Evergreen	72,170	61,524	50,869	40,244	29,790
Country Gentleman	68,912	58,746	48,571	38,420	28,380
Stowell Evergreen	74,819	63,823	52,808	41,818	30,973
1925					
Golden Bantam (Stokes)	63,637	54,397	45,157	35,931	26,861
Stowell Evergreen (Stokes)	76,101	65,061	54,021	42,997	32,219
Guatemalan (U. S. D. A.)	91,292	77,749	64,274	51,149	38,399
Second Early Adams (dent; Bolgiano)	65,958	56,478	46,998	37,532	28,222
1926					
Golden Bantam (Stokes)	64,308	54,950	45,558	36,177	27,488
Stowell Evergreen (Iowa)	79,425	67,547	55,635	43,734	32,523
Stowell Evergreen (Arlington Experiment Farm)	81,337	69,219	57,067	44,926	33,475
Country Gentleman (Iowa)	74,646	63,608	52,536	41,475	31,106

Since the minimum-temperature base lines for all these varieties are not known, the full significance of these summations can not be completely determined, but some interesting comparisons are possible. It is noted that in the case of Stokes strain of Golden Bantam grown during the seasons of 1925 and 1926 the summations above 55° F. differ for the two years by only 246 degree-hours, the average summation being 36,054 degree-hours. This suggests 55° as the probable minimum air-temperature base line for this strain, as both above and below this base line the summations differ much more widely.

The same variety, but from a different source, grown during 1922 at none of the base lines used in these tests, shows a summation approaching that of the corn just mentioned, and obviously indicates a distinct strain difference in seed. It is of interest to note that this corn required less temperature to reach canning maturity than any other variety or strain of the same variety grown during the period of 1922 to 1927, with the single exception of the 1924 Golden Bantam above the base line of 60° F.

In Table 8 are shown summations also for four different plantings of Stowell Evergreen. Considerable variation is seen in the summations above the 60° F. base line, with a range of 2,502 degree-hours between the strain grown in 1922 and the Arlington Experiment Farm strain grown in 1926. It is of interest that the Stokes strain of 1925 and the Iowa strain of 1926 vary by only 304 degree-hours in their

temperature requirements above the 60° base line, the average summation for these two plantings being 32,371 degree-hours. This suggests the possibility that the seeds of these two plantings were derived from plants of the same strain.

Some idea of the relative temperature needs of other varieties of sweet corn may be obtained from a comparison of their summations for the year 1922 with those of the Golden Bantam and Stowell Evergreen. They were grown in the same field under as nearly identical environmental conditions as were practicable.

Within the 1925 group attention is called particularly to the very great summations of prevailing temperature in the case of the Guatemalan corn, which were far in excess of those of any variety of sweet corn studied by the writers.

The summations for the two plantings of Country Gentleman for the period from planting to canning maturity were much greater for the 1926 corn than for the corn grown in 1922.

The response of different strains to temperature conditions above various base lines in 1927 is shown clearly in the summations of Table 9.

TABLE 9.—*Air-temperature summations for different pedigreed strains of Country Gentleman and Golden Bantam sweet corn grown at the Arlington Experiment Farm, 1927*

[Based on data for the period from planting to canning maturity]

Variety and strain	Degree-hours above base line of—				
	40° F.	45° F.	50° F.	55° F.	60° F.
Country Gentleman:					
No. 1	74,019	62,544	51,181	39,999	29,356
No. 2	72,769	61,610	50,494	39,507	29,025
No. 3	74,605	63,010	51,552	40,255	29,539
Golden Bantam:					
No. 1	68,491	58,170	47,851	37,582	27,718
No. 2	68,491	58,170	47,851	37,582	27,718
No. 3	70,893	60,212	49,533	38,904	28,681

These data were obtained from plants of pedigreed strains of the Country Gentleman and Golden Bantam varieties, the seed of which were kindly supplied by G. N. Hoffer of the Indiana Agricultural Experiment Station. These corns were grown side by side in the same field, and environmental conditions were identical for all. The three strains of Country Gentleman vary within a range of about 500 degree-hours above the 60° F. base line and take an intermediate position between those considered in Table 7. This variation is not great but nevertheless is well defined. More striking are the figures for the three strains of Golden Bantam, for No. 1 and No. 2 showed exactly the same temperature requirements, whereas No. 3 required considerably more heat to bring it to canning maturity than its associates in the test.

DATA FROM CORN GROWN IN IOWA

Temperature summations have been made for different varieties of sweet corn grown at the Iowa Agricultural Experiment Station, Ames, Iowa, during 1925 and 1926. The field data for these corns and samples for chemical analysis were supplied through the courtesy of A. T. Erwin of that station. The planting, mid-silking, and sam-

pling dates were derived from the field records, and canning maturity was determined from the results of chemical analysis of the samples prepared from the corn at different stages of maturity. The temperature data are based on the official Weather Bureau reports for Des Moines, which is approximately 30 miles south of Ames and has a normal mean temperature about 1½ degrees above that for Ames. (See normal temperature curves in Figure 10.) The summations, therefore, are probably a little higher than would have been obtained had actual Ames records been used. It is believed, however, that these differences are not great enough to affect seriously the results obtained. Slight errors in these summations may likewise be present, due to the fact that they are based on the daily mean temperature rather than on the hourly readings as in the Arlington Experiment Farm data. The summations for the period from planting to canning maturity are presented in Table 10, and the curves of the temperatures for the growing seasons of 1925 and 1926 are shown in Figure 10.

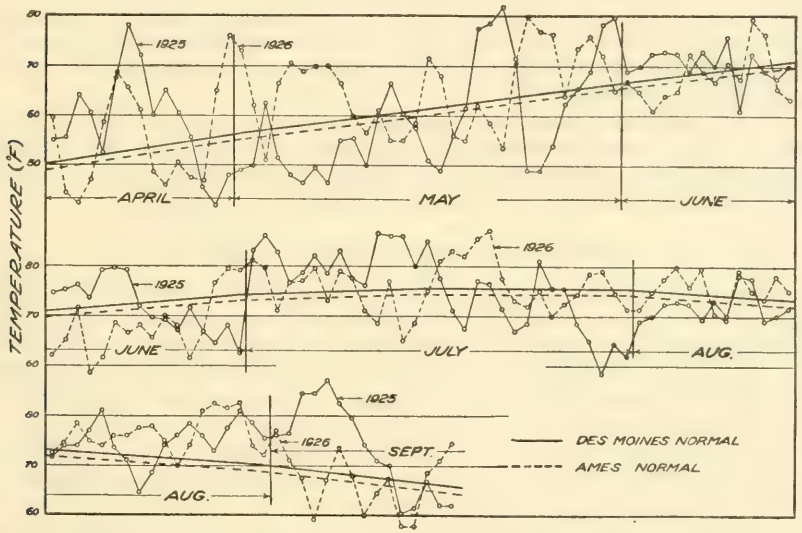

FIGURE 10.—Mean daily temperature curves for Des Moines, Iowa, during the period from April 16 to September 15, inclusive, for the years 1925 and 1926. Curves for the normal mean temperatures for Des Moines and Ames, Iowa, are also shown. (Data from U. S. Weather Bureau records)

TABLE 10.—*Air-temperature summations for sweet corn grown at Ames, Iowa, 1925 and 1926*

[Based on data for the period from planting to canning maturity]

Year and variety	Degree-hours above base line of—				
	40° F.	45° F.	50° F.	55° F.	60° F.
1925					
Golden Bantam	73,856	61,858	50,060	39,122	28,164
Golden Giant	82,784	69,756	56,338	44,078	31,800
Golden Evergreen	87,644	73,824	59,626	46,766	33,768
Stowell Evergreen	88,736	74,806	60,418	47,510	34,392
1926					
Golden Bantam	67,620	56,892	46,020	35,256	25,020
Country Gentleman	82,476	69,228	56,796	43,992	31,716
Stowell Evergreen	91,848	77,076	63,084	48,720	34,908

It is seen at once that the Golden Bantam corns grown during these two seasons differed considerably in their response to temperature conditions, that grown in 1925 showing a summation above the assumed minimum temperature of 50° F. 4,040 degree-hours greater than that grown during 1926. There is no close agreement in the summations above any base line considered, and it seems safe to assume that these corns represent two distinct strains. The two plantings of Stowell Evergreen, on the other hand, showed summations above the assumed base line of 60° for the two seasons varying by only about 500 degree-hours. It would appear that the seed of these two plots was derived from the same strain of corn.

Comparing these figures of Table 10 with those obtained at the Arlington farm from Iowa seed (Table 8), it is found that the Stowell Evergreen grown in Iowa in 1926 had a temperature summation above the 60° F. base line approximately 2,400 degree-hours greater than that grown at the Arlington farm during the same season. Whether the seed of these two plantings was derived from the same lot is not known. In the case of the Country Gentleman variety, however, the Iowa-grown corn required only slightly over 600 degree-hours more than that grown at the Arlington farm, considering 60° as the probable proper base line.

The possible relation of regional factors to the behavior of the corns can not be proved conclusively, but the fact that the Iowa figures shown here are always somewhat higher than those obtained at the Arlington farm should be noted in passing.

DATA FROM CORN GROWN IN MAINE

The study of corn grown in Maine was confined to different strains of one variety of sweet corn—Crosby—in the portion of the Androscoggin River Valley lying between Rumford on the north and Durham on the south, a farming section characterized by widely varying types of soils and topographical conditions. In some instances the corn was grown on very light sandy soils, in others on heavy clay loams; it was also grown on all intermediate types of soil. The elevations of the different farms varied by as much as 500 feet in some instances. Obviously, it was not possible to secure accurate temperature records on all these farms, and it was necessary to rely on the official records of the nearest Weather Bureau station, located at the gatehouse of the Union Water Power Co., at Lewiston. This station is not in the center of the region concerned, but is approximately 5 miles from the southern boundary. Auburn lies directly across the river from Lewiston, and the farms listed under this name lie within a radius of about 5 miles from the Weather Bureau station. North Turner is about 12 miles north of this point, Livermore Falls approximately 30 miles to the northeast, and Dixfield approximately 35 miles north of the station. It is inevitable, therefore, that the summations for these more distant locations, based on the Lewiston temperature data, should be slightly too high. This influence of distance from the recording station will be noted in the data to be presented, but is not sufficiently great to affect the results seriously.

These summations are for the period from planting to the date of delivery to the factory. Theoretically, corn as delivered at the factory should be at a very definite stage of maturity, and in the majority of cases this condition is closely approximated. However, weather conditions sometimes interfere with the harvesting of the crop at the appointed time, and in a few individual cases the operation of other factors may result in the corn being delivered when slightly immature or slightly overmature. Small errors in summations may arise from these causes, but it is believed that in the present cases these errors are very small.

Data for two seasons will be given; those for 1925, when figures from 10 different farms in the region about Auburn were obtained, and for 1926, when corns from 72 farms within the larger area were included in the study.

The summations are based on hourly temperature readings made throughout the season.

Table 11 shows the results obtained for the season of 1925 in the Auburn region.

TABLE 11.—*Air temperature summations for different strains of Crosby sweet corn grown near Auburn, Me.*

[Based on data for the period from planting to canning maturity]

Strain and farm	Degree-hours above base line of—				
	40° F.	45° F.	50° F.	55° F.	60° F.
Burnham & Morrill Clark strain:					
James farm	70,007	55,642	41,961	28,560	17,530
Sanborn farm	69,816	55,535	41,914	28,550	17,530
Early Crosby strain:					
Redmond farm	59,506	47,498	36,013	24,512	15,274
Johnson farm	67,534	53,856	40,888	28,063	17,321
Ellis strain:					
Packard farm	63,621	51,082	39,070	26,986	16,763
Flanders farm	62,565	49,833	37,698	25,627	15,578
Mower farm	67,458	53,850	40,844	27,928	17,221
Finn strain:					
Taber farm	59,664	47,845	36,554	25,086	15,358
Osgood farm	61,851	49,249	37,301	25,363	15,417
Harper farm	63,401	50,742	38,610	26,456	16,324
Average	64,542	51,513	39,085	26,713	16,432

Four strains of Crosby corn are represented in these figures. Differences in strains as regards their response to temperature conditions are indicated, but the data are too few to warrant general conclusions on this point. Differences in soil conditions on which the corns were grown and in elevation doubtless account for the variations noted within each group. The average summations for the 10 fields of corn calculated above the various base lines should be noted.

Table 12 shows the results obtained from 72 different farms during the season of 1926 within the larger area mentioned.

TABLE 12.—*Temperature requirements of different strains of Crosby corn grown in Maine, 1926*

[Based on temperature data for Lewiston for the period from planting to canning maturity]

Strain and locality	Field No.	Degree-hours above base line of—				
		40° F.	45° F.	50° F.	55° F.	60° F.
Ellis strain:						
Dixfield	1	66,222	51,918	37,960	25,226	14,884
	2	64,975	50,980	37,707	25,132	14,871
	3	65,302	51,118	37,446	24,848	14,632
	4	65,495	51,311	37,888	25,210	14,884
	5	62,760	49,169	36,087	24,034	14,233
	6	67,601	52,729	38,232	25,382	14,976
	7	62,239	48,839	36,244	24,283	14,397
	8	62,239	48,839	36,244	24,283	14,397
	9	65,578	51,515	37,683	25,146	14,886
	10	64,698	50,885	37,323	24,922	14,742
	11	66,552	52,103	37,857	25,239	14,910
	12	64,539	50,664	37,220	24,765	14,619
	13	63,729	50,016	36,783	24,538	14,536
	14	66,219	51,675	38,006	25,224	14,884
	15	66,230	51,914	37,897	25,189	14,880
	16	65,487	50,839	37,277	24,962	14,787
	17	65,578	51,515	37,713	25,146	14,886
	18	65,084	51,224	37,501	25,117	14,871
Average		65,029	50,958	37,393	24,925	14,737
Livermore Falls	1	61,016	48,033	35,435	23,800	14,171
	2	63,747	50,112	36,955	24,658	14,602
	3	64,732	50,684	37,331	24,951	14,800
	4	61,494	48,571	35,896	24,211	14,470
	5	64,880	50,509	37,381	24,976	14,747
	6	63,810	50,320	37,031	24,801	14,710
	7	64,127	50,789	37,307	24,937	14,772
Average		63,401	49,859	36,762	24,619	14,610
North Turner	1	60,232	48,108	35,599	24,045	14,358
	2	62,520	49,559	36,574	24,602	14,642
	3	64,199	50,608	36,938	24,613	14,556
	4	63,119	49,957	36,634	24,507	14,541
	5	61,876	49,238	36,249	24,335	14,441
	6	65,878	51,815	37,833	25,196	14,916
	7	62,557	50,161	36,932	24,784	14,708
	8	64,678	50,837	36,928	24,552	14,536
	9	61,104	48,095	35,281	23,708	14,136
	10	63,729	50,366	36,783	24,538	14,536
Average		62,989	49,874	36,575	24,488	14,537
Auburn	1	58,647	46,842	34,658	23,419	13,998
	2	62,733	49,784	36,571	24,478	14,473
	3	67,606	52,774	38,281	25,341	14,946
	4	60,242	47,764	35,100	23,630	14,123
	5	63,729	50,366	36,783	24,538	14,536
	6	61,482	48,761	36,016	24,279	14,492
Average		62,407	49,381	36,234	24,281	14,428
Average for Ellis strain		63,870	50,276	36,672	24,672	14,622
Burnham & Morrill Clark strain:						
North Turner	1	63,654	50,761	36,416	24,479	14,612
	2	65,232	53,771	38,415	25,366	14,961
	3	63,982	50,409	37,031	24,801	14,710
	4	69,132	53,930	38,455	25,416	14,991
Average		65,500	52,218	37,579	25,016	14,819
Auburn	1	65,332	51,439	37,357	24,862	14,787
	2	68,156	54,103	38,281	25,241	14,946
	3	62,692	49,559	36,574	24,602	14,642
Average		65,393	51,700	37,404	24,901	14,792
Average for Burnham & Morrill Clark strain		65,454	51,996	37,504	24,967	14,807

TABLE 12.—*Temperature requirements of different strains of Crosby corn grown in Maine, 1926*—Continued

Strain and locality	Field No.	Degree-hours above base line of—				
		40° F.	45° F.	50° F.	55° F.	60° F.
Early Crosby strain:						
Livermore Falls	1	65,332	51,439	37,357	24,926	14,787
	2	66,006	51,913	37,751	25,192	14,916
Average		65,669	51,676	37,554	25,059	14,851
North Turner	1	64,982	51,209	37,231	24,901	14,770
	2	66,008	51,466	37,350	24,775	14,617
Average		65,495	51,337	37,291	24,838	14,693
Auburn	1	61,457	48,415	35,525	23,799	14,161
Average for Early Crosby strain		64,757	51,473	37,043	24,719	14,650
Finn strain:						
Livermore Falls	1	60,352	48,029	34,916	23,549	14,093
	2	66,901	52,289	38,032	25,232	14,886
	3	65,732	51,809	37,381	24,976	14,815
Average		64,328	50,709	36,776	24,586	14,598
Nolan Early Crosby strain:						
North Turner	1	64,227	50,274	36,645	24,422	14,481
	2	61,261	48,449	35,742	24,080	14,358
	3	62,256	49,311	36,475	24,585	14,640
	4	61,654	48,761	36,016	24,279	14,492
	5	64,552	50,608	36,938	24,613	14,556
	6	64,093	50,458	37,015	24,733	14,617
	7	62,986	49,275	35,893	23,916	14,176
	8	65,276	50,972	37,056	24,627	14,556
	9	65,059	50,995	37,205	24,761	14,617
	10	61,602	48,353	35,375	23,722	14,136
Average		63,297	49,746	36,436	24,374	14,463
Roake strain:						
Auburn	1	60,242	47,542	34,967	23,561	14,100
	2	60,584	47,764	35,100	23,630	14,123
	3	61,146	48,128	35,305	23,711	14,135
	4	61,402	48,291	35,395	23,749	14,141
	5	63,041	49,212	35,776	23,885	14,208
Average		61,283	48,187	35,309	23,707	14,141
Martin strain:						
Auburn	1	61,769	48,735	35,847	24,078	14,322
Grand average		63,816	50,264	36,644	24,584	14,581

In view of the factors contributing to variations in results that have been pointed out, one is impressed by the striking uniformity in the summations above the various base lines. Variations due to distance from the weather-recording station are shown most satisfactorily in the figures for the Ellis strain and amount to a few hundred degree-hours between the group nearest to and that farthest from the recording station.

The temperature requirements of the different strains did not vary widely, though the Roake corn used somewhat less heat than any of the others.

In comparing the averages for this season (1926) with those for 1925 it is seen that all strains matured with less heat in 1926 than they required the previous year. It is possible that the smaller number of observations in 1925 may be partly responsible for this variation, but it is not believed that this accounts for all the difference. The 1925 season in this region was one including prolonged drought,

and it is probable that here, as in the case of the Stowell Evergreen grown at the Arlington farm in 1924, the normal rate of development was retarded from this cause and a higher temperature summation resulted.

In order to evaluate these results for future use it is necessary to know something about the minimum temperature base line for Crosby corn. A limited number of plantings of Crosby corn have been made at the Arlington farm, and their temperature requirements will be shown later; but it is not possible from the data to tell what is the minimum-temperature base line for this variety. It is well known, however, that Maine growers of sweet corn are narrowly restricted as to planting dates because of the short growing season. Too early planting results in the rotting of the seed in the ground, and late planting exposes the corn to the danger of killing frost before it arrives at canning maturity. Practical experience has shown that it is necessary for Maine growers to plant their corn at a time when the prevailing temperature is close to the minimum for this crop. On this basis, it is possible to determine reasonably closely the minimum temperature for Crosby corn.

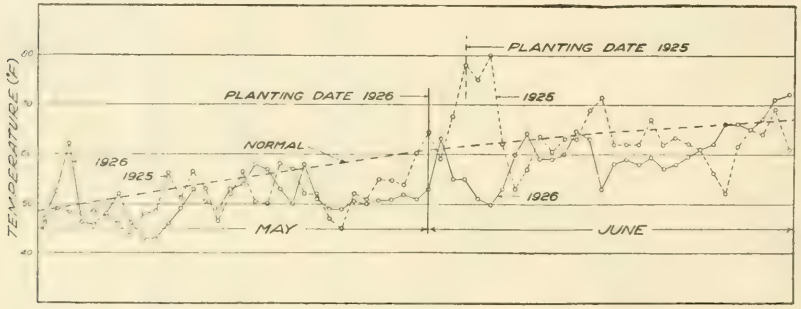

FIGURE 11.—Mean hourly temperature curves for Lewiston, Me., during May and June, 1925 and 1926, as recorded at the Union Water Power Co.'s gatehouse. The normal temperature curve for this station is also shown

In Figure 11 are shown the mean daily temperature curves based on hourly readings for Lewiston for May and June, 1925 and 1926, with the average date of planting each year.

For both seasons the temperature during May was, for the most part, below normal for that region. For about 10 days during the middle of the month the air temperature averaged well above 50° F. and then fell slightly below this point for a short time before swinging upward. Plantings were made shortly after the temperature began to move upward again. The practical experience of these farmers indicated an air temperature of close to 50° as unsafe for the germination of the corn, and a study of the chart shows that the soil temperature at the time of planting must have been fairly close to 50°. A personal communication from a representative of one of the corn-canning companies operating in this region states that normally May 25 is about the average planting date for this region. The normal temperature curve for this date stands at about 57°. It seems reasonable to conclude, therefore, that 55° air temperature or 50° soil temperature is close to the minimum-temperature base line for Crosby corn. Assuming this to be the case, it is found by reference to Tables 11 and 12 that the air-temperature requirement of Crosby corn for

the period from planting to delivery of corn to the cannery averaged 26,713 degree-hours above 55° in 1925 and 24,584 degree-hours in 1926. For comparison with these results the data obtained from different strains of Crosby corn grown at the Arlington farm are presented in Table 13.

TABLE 13.—*Air-temperature summations for different strains of Crosby corn grown at the Arlington Experiment Farm, Rosslyn, Va., 1922, 1926, and 1927*

[Based on data for the period from planting to canning maturity]

Year and strain	Degree-hours above base line of—				
	40° F.	45° F.	50° F.	55° F.	60° F.
1922					
Early Crosby	65,274	55,588	45,893	36,227	26,700
1926					
Burnham & Morrill Clark strain (from Maine)	62,465	53,505	44,253	35,112	26,703
Crosby (from Minnesota)	65,226	55,686	46,054	36,433	27,504
1927					
Crosby No. 28697	66,593	56,393	46,203	36,118	26,486
Early Crosby No. 28693	66,022	55,942	45,872	35,898	26,352
Minnesota Crosby No. 28695	66,022	55,942	45,872	35,898	26,352
Average	65,267	55,509	45,691	35,948	26,683

Comparing the Maine-grown corn with that grown at the Arlington farm, it is seen that from the 55° F. base line the average summations are considerably less; that is, 24,584 degree-hours as against 35,948 degree-hours. These results, however, include data for several strains grown in different years in each case.

In order to get a strict comparison of the behavior of corn grown in Virginia and in Maine, attention is called to the data of the Burnham & Morrill Clark strains grown in these two regions from the same lot of seed. Comparison of the data from the 55° F. base line shows that corn grown in Maine reached canning maturity with a temperature summation of 24,967 degree-hours, as against 35,112 degree-hours for that grown at Arlington farm, a difference of 28.9 per cent. If comparison is made of the data at the lower base lines it is found that the difference becomes progressively less as lower base lines are used, until the two gradients cross, giving at the 40° base line a summation greater for the Maine-grown corn. This might seem to throw doubt on the validity of the use of the 55° base line in this consideration, but it must be noted that in Maine there is a greater accumulation of ineffective low temperature than in Virginia, and possibly a greater accumulation in ineffective high temperature in Virginia than in Maine, which would tend to explain, in part at least, these differences in results.

From the data presented it is concluded that for Crosby corn 55° F. is the most appropriate base line. From the use of this line with the Maine and Virginia data it appears, as has already been suggested, that the response to temperature conditions of the corn grown in Maine is distinctly different from that grown in Virginia. As factors probably important in contributing to this result may be mentioned difference in length of day (which provides for longer

periods of photosynthetic activity), a lower rate of respiration under Maine conditions, and a better balance between photosynthesis and transportation of manufactured plant products, as suggested by Livingston and Livingston (*10*).

DATA FROM CORN GROWN IN NEW YORK

There remain to be considered only a few data on corn grown at Mount Morris, N. Y., during 1926. So few are the data that they would not be presented here but for the fact that they show again how much more economical of temperature are corns grown in the northern latitudes of the country. The variety here was Red-leaved Evergreen,[2] which was planted on June 1 and came to canning maturity on October 13. The air-temperature summations for this corn are

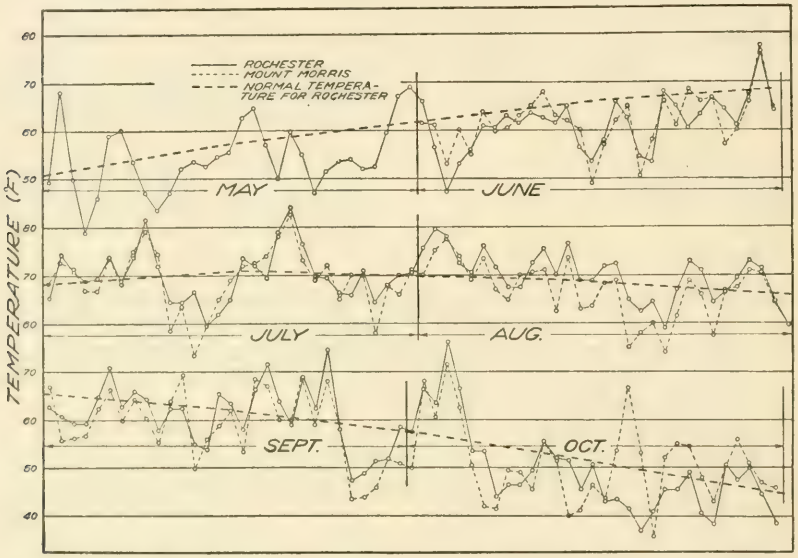

FIGURE 12.—Mean daily temperature curve for Rochester, N. Y., for the period from May 1 to October 31, 1926, inclusive, and for Mount Morris, N. Y., for the period from June 1 to October 31, inclusive, of the same year from data for Rochester taken from the U. S. Weather Bureau records and data for Mount Morris taken from field records

as follows: At 40° F., 75,113 degree-hours; at 45°, 59,129 degree-hours; at 50°, 43,673 degree-hours; at 55°, 29,404 degree-hours; at 60°, 16,868 degree-hours.

In order to interpret these figures properly it is necessary to know something of the minimum-temperature base line of this corn. It is regretted that more information on the temperature requirements of this particular variety in various parts of the country is not available, but a brief study of local conditions where this corn was grown serves to throw light on this point. In the present case temperature records were begun on the day of planting and continued through the growing season. In Figure 12 these records are charted; and to throw some light on conditions prior to the planting date, the records for Rochester, N. Y., where the nearest Weather Bureau station is located, are also charted for the season of 1926, and the normal

[2] According to information obtained from growers of this corn, it is a late variety closely resembling Stowell Evergreen.

temperature curve is also shown. The daily mean temperature at Rochester and Mount Morris averaged about the same during this season with the exception of August, when the Mount Morris temperatures averaged a little lower than those of Rochester. It is believed, therefore, that the normal temperature curve for Mount Morris would not differ greatly from that for Rochester.

This corn was planted when the air temperature was a little above 60° F., and during this season the temperature for the first three weeks of June averaged close to this temperature. A personal communication from a representative of one of the canning companies operating in this region states: "We have not been able to plant any corn here in the Mount Morris district much before May 20." Data from another source place the average planting date, prior to the invasion of the territory by the European corn borer, at about May 20. The chart shows that the normal temperature for this date is about 58.5°, only slightly below the average temperature of the first three weeks in June, 1926. While this does not prove the minimum air temperature of this corn to be 60°, it does indicate that this can not be far from the minimum. The summation above this base line was 16,868 degree-hours, which was far less than that of any variety grown at the Arlington farm during the years these studies have been carried on.

GENERAL DISCUSSION

The value of any system for determining the response of plants to their temperature environment must be dependent upon its appropriateness when applied to practical conditions. Experience has indicated that absolutely uniform and exact results are not to be expected from any system, for the reason that many and widely varying factors are involved, and it is extremely difficult if not impossible at the present stage of knowledge to evaluate the influence of any one factor in plant behavior as distinct from that of all other factors. The present use of the system of "remainder" indices and the determination of the minimum standard deviation from the mean summations above various base lines is not entirely satisfactory, since here, as in the use of other systems, it is impossible to rule out entirely the effect of prolonged drought and some other variable influencing factors, which, in the present case, tend to increase the standard deviation and obscure its significance. It is believed, however, that much of the objection to, and the inconsistencies of, the remainder system may be eliminated by the use of suitable temperature base lines, and it is believed that the present method of determining these base lines will be found useful and reasonably satisfactory in the study of crop behavior.

It is to be noted that a base line as here determined does not mean that absolutely no growth or development will take place below that base line; but it does serve as a practical zero point. It operates to eliminate the ineffectiveness of low temperatures and the inefficiency of temperatures close to the base line. The slight effectiveness of the temperatures below the base line is mathematically balanced by the inefficiency of the temperature just above the base line. It seems to be, therefore, the best compromise that can be obtained where all the environmental factors are taken into consideration.

It may be objected that the methods employed here in the calculation of the temperature requirements of corn are too laborious for general application to the study of various crops and that sufficiently satisfactory results might have been obtained in the present case by using the daily mean temperature as the basis of calculations rather than the hourly readings. It is true that the hourly readings are not generally available and daily means must often be used if studies of this kind are to be carried on. In the case of the Iowa and the New York data presented here, only daily maxima and minima were available. It is well known, however, that the mean daily temperature, representing as it does the average of the recorded maximum and minimum temperatures, does not always give an accurate measure of the amount of heat received from the sun during the day. In endeavoring to establish the proper minimum-temperature base lines for corn, therefore, the more laborious calculations were used, in the belief that the greatest possible accuracy was required. For crops having longer growing seasons or for those less sensitive to daily temperature variations closely comparable results would doubtless be given by the use of either daily means or hourly readings as the basis of calculations. No attempt has been made in the present case to check the differences with corn.

Criticism of the material presented here may also be lodged by plant physiologists and others on the ground that in the calculations of the summation data no account was taken of so-called temperature efficiencies. Price (*14*) was among the first to emphasize the possible relation of the Van't Hoff-Arrhenius principle concerning the velocity of chemical reactions as affected by changes in temperature to the response of plants to their climatic environment. He found the principle to hold generally for the opening of the flower buds of plums, peach, apple, and other fruits, and pictured maize seedlings germinated at different temperatures, which suggested that the principle might also hold for maize. Making use of this principle in their calculations, Livingston and Livingston (*10*) prepared a table of "efficiency indices" for temperatures between 40° and 99° F., and in a careful and extensive study they proceeded to compare the results obtained by the use of these indices with those derived by the use of the time-honored direct summation methods then in common use by phenologists. It appears very significant that the two methods employed for estimating temperature effectiveness gave results agreeing within a plus or minus variation no greater than 5 per cent for most of the area of the United States. Convinced of the soundness of the view that the rate of growth in plants is a function of the temperature, and supported by the observations of Lehenbauer (*8*) on the rate of growth in maize seedlings at different temperature levels, Livingston (*9*) later developed a new set of indices which, taking into account the Van't Hoff-Arrhenius principle, recognized not only a minimum and a maximum temperature for plant growth but also an optimum temperature beyond which the rate of growth was retarded progressively until the maximum was reached. These so-called "physiological" indices have been employed by various investigators engaged in the study of the temperature relations of plants. Reports of these studies, however, by no means confirm the uniform adaptability of these indices to the interpretation of practical field data. Thus, Appleman and Eaton (*1*) reported that the physiological indices did

not furnish even an approximate criterion of the temperature efficiency for the ripening processes in sweet corn. The Van't Hoff-Arrhenius principle, however, was found operative, the so-called "efficiency" or "exponential" indices of Livingston and Livingston (*10*) heretofore mentioned proving useful for their study. "Direct" summations of degree-hour units, comparable to the "remainder" summations used in this bulletin but involving the use of 40° F. as the base line, showed slightly higher figures for the late than for the early crop, but the discrepancies were thought to be due in part to the conditions under which the temperature records were secured.

In this connection it should be remembered that conditions that stimulate growth may be very different from those that determine the length of the reproductive cycle in the plant. The present study is concerned with the reproductive cycle. The reproductive processes are preceded, of course, by a period of growth which may greatly affect the yield, but the rate of growth does not necessarily determine the length of the reproductive cycle. Furthermore, the growth response of seedlings to varying conditions of temperature may be very different from the growth response exhibited by plants approaching the period of reproduction. It seems doubtful, therefore, whether the results of Lehenbauer (*8*) are applicable to the processes here under consideration.

Of particular interest is the report of work done by Hanna (*6*) on Northwestern dent corn (*Zea mays*) and Mammoth Russian sunflower (*Helianthus annuus*). This investigator made careful comparison of the various temperature efficiency indices in his analysis of the responses of these plants to climatic factors and found that corn gave the best correlation with temperature when remainder indices derived from temperatures above 10° C. (50° F.) were employed. Sunflowers gave the best correlation with temperature above 0° C. (32° F.). Noting a better correlation between the growth of corn and the physiological indices than was obtained with sunflowers, he made the highly important observation that "physiological temperature efficiency indices for expressing plant growth can be of little value unless derived from observations on the particular kind of plants under consideration." This work of Hanna confirmed the observation of Lehenbauer (*8*), which seems to have been entirely ignored in the development and use of the physiological indices, that the minimum temperature for corn was close to 12° to 14° C. (53.6° to 57.2° F.). The results presented here are in striking agreement with the findings of these investigators.

These physiological temperature-efficiency indices were developed for use primarily in the study of plant geography as related to climate, and it is probable that their application to the study of the response of specific crops to temperature was not anticipated. Their chief shortcoming for such use probably lies in the fact that 40° F. (4.4° C.) is not the minimum temperature of many plants and 89.6° F. (32° C.) does not coincide with the optimum of many of them. This is indicated not only by the results of the present study with corn but also by the findings of Hanna (*6*) with corn and sunflowers, mentioned above, of Tottingham (*15*, *16*) with red clover (*Trifolium pratense*), buckwheat (*Polygonum fagopyrum*) and wheat (*Triticum vulgare*), and of Hardenburg (*7*), Bushnell (*4*), and others with potatoes (*Solanum tuberosum*). Although the Van't Hoff-Arrhenius

principle seems not to have been considered by some of these latter workers in the interpretation of their experimental data, it seems reasonable to question, from the reports of their findings, whether this principle is applicable in the study of storage processes, particularly in some common forage and food plants. The optimum temperature for enzymic activity varies widely in nature, and temperature conditions well suited to vegetative developments in plants may be unfavorable for other physiological activities. That the rate of respiration varies with different temperatures is, of course, well known, and that this factor enters into storage relationships must be recognized.

Boswell (*2*), in the report of his study on the influence of temperature upon the growth and yield of garden peas, made use of summations above the base line of 40° F. He stated that peas showed little if any correlation between the total degree-hours of heat above 40° and the time required to reach blossoming, but rather showed that in a given season blossoming occurs upon the reception of a fairly constant amount of heat regardless of time. It is well known that peas for best growth require a lower temperature range than corn, and the 40° base line doubtless is close to the true minimum for this crop.

In a later paper Boswell (*3*) reported on a study of the temperature influence upon chemical composition and quality of peas, in which it was noted that no consistent relationship could be observed between mean temperature and chemical composition, but there was a very good correlation between temperature summations and the starch-sugar ratios. Results were not uniform for all the seasons in which the work was done, however, and strain differences, varying nutritional conditions, and differences in day length were offered as possible explanations.

Mention has been made in this bulletin of the evident slowing down of physiological processes in corn as the result of soil-moisture deficiency, and some data have been presented in support of this. During 1930 abundant opportunity was afforded to observe the effect of drought on plant processes, and conversations with physiologists have indicated that the slowing down of plant activity as a result of water deficiency has been widely noted.

The greatly differing temperature requirements of corn grown in northern sections of the country and that grown in the experiment plots in Virginia call for further brief consideration. In the discussion of this subject in connection with the examination of the Maine data, day length and the balance between photosynthetic activity and translocation of synthesized plant products as affected by temperature levels were mentioned as probably accounting for the more economical use of temperature by the Maine-grown corn. There remain to be considered two other factors that may have had some bearing on this result.

Reference has been made to the relation of temperature levels to respiration and storage processes in plants. Since the corn grown at the Arlington farm was grown within a climatic temperature range considerably above that of Maine and western New York, it is reasonable to assume a higher rate of respiration in the corn grown in Virginia, and consequently the use of a greater amount of heat by this corn. Such an assumption is in line with the observed facts. The

second consideration has been suggested by the work of Long (*11*) on the relation of light to photosynthetic activity in plants. This worker found that not only was this activity affected by different degrees of light intensity but that the quality of the light also had a very definite effect upon the rate of photosynthesis. Red light was found to be much more favorable for photosynthesis than blue. Since the rays of the sun are more oblique in the northern latitudes than in the southern, normal sunlight there contains more of light from the red end of the spectrum than does that of the more southern sections of the country. How significant this possible factor is in plant activities is not known, but if significant at all its effect would be in the direction of the observed findings of the present study. This might help to explain also the more economical use of temperature by the late plantings of Virginia-grown corn which became increasingly apparent concomitantly with the shortening of the day.

SUMMARY

This bulletin records the results of studies on the response of different varieties and strains of sweet corn to varying temperature conditions. For this work use was made of official Weather Bureau and field temperature records and data derived from plantings of corn grown at the Arlington Experiment Farm, Rosslyn, Va., near Washington, D. C., during 1922, 1924, 1925, 1926, and 1927, and from corns grown in Iowa and Maine during 1925 and 1926 and in western New York in 1926.

By using the so-called "remainder" system, summations of the prevailing temperatures above various base lines have been calculated and the results expressed in terms of degree-hours (Fahrenheit). Wherever possible, hourly temperature readings rather than the daily mean were used as the basis of calculations.

An attempt has been made to determine the temperature base line most appropriate for use with the remainder system in studying the response of corn to temperature conditions, which has been accomplished by considering as most valid that base line the summations above which showed the smallest standard deviation from the mean for corns grown under widely varying temperature conditions. To obtain data suited for this purpose, plantings of Golden Bantam and Stowell Evergreen varieties were made at intervals of a week to 10 days during 1924 and 1927 at the Arlington Experiment Farm, and the behavior of these corns with relation to the varying seasonal conditions was determined. The applicability of these data to the problem under consideration has been shown by comparison with similar data from a hypothetical case giving theoretical values. The results are set forth in tables and illustrated by graphs.

Experimental findings have been found to agree significantly well with the theoretical, though conditions of drought, abnormally high and prolonged summer temperatures, variable day length, and other factors causing variations in the summation curves have in some cases increased the standard deviations and tended to obscure somewhat their real significance.

The evidence here set forth indicates that at least where the remainder system for studying the temperature response of sweet corn is used a 40° F. air-temperature base line is much too low and suggests

the probability that this temperature is considerably below the true physiological minimum for this crop.

The most satisfactory air-temperature base line was found to vary with different varieties and strains, in the case of those corns under study falling within the range of 50° to 60° F., indicating that the amount of heat required to bring sweet corn to canning maturity varies not only with different varieties but with strains within the varieties.

With the use of soil temperatures as the basis for calculations, the most satisfactory base lines were found to fall approximately 5° F. below those for air temperatures under conditions at the Arlington Experiment Farm.

The observation that some corns apparently have lower minimum temperature requirements than others suggests that not only may such corns be particularly adapted for growing in regions having short growing seasons but might be planted at decidedly earlier dates than are commonly set for planting in various regions.

Corn subjected to drought conditions did not show as great a developmental response to prevailing temperatures as the same variety and strain enjoying ample rainfall. Thus the amount of heat required to bring the corn to canning maturity appeared to be increased.

Corn arriving at canning maturity near the close of the season showed a lower summation of effective-temperature units than that maturing earlier in the season.

With the use of the same temperature base lines for the same varieties of corn grown in Maine and New York as at the Arlington Experiment Farm, it was found that the northern-grown corn came to canning maturity with a far smaller temperature-unit summation than that grown in Virginia. Corn of an identical strain grown in Maine and at the Arlington farm during the same season yielded results agreeing closely with those just mentioned. Differences in the rate of respiration in the corn growing within different temperature ranges, differences in the length of day permitting longer periods of photosynthetic activity in the northern regions, a better balance between photosynthesis and the transportation processes in the movement of manufactured plant products, and difference in light intensity and the quality of the sunlight are suggested as possible factors involved in this result.

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TECHNICAL BULLETIN NO. 311 JUNE, 1932

ADEQUACY AND RELIABILITY OF CROP-YIELD ESTIMATES

BY

CHARLES F. SARLE

Formerly Senior Agricultural Statistician and Member of the Crop Reporting Board
Division of Crop and Livestock Estimates, Bureau of
Agricultural Economics

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CONTENTS

	Page
Introduction	1
Purpose and procedure	4
Sources and kinds of information	5
Phenomena of crop-yields	5
The lists of reporters	7
Judgment inquiries	8
Reports for individual farms	9
Census enumerations	10
Commercial checks	11
Preparation of the estimates	11
Adequacy of sample data	12
The problem	12
Representativeness of yield samples	15
Methods of selecting a representative sample	19
Errors encountered and their treatment	23
Measures of precision of averages	28
Statistical induction	36
Reliability of the estimates for selected crops	39
Procedure	40
Winter wheat	46
Spring wheat	56
Rye	60
Corn	63
Oats	70
Barley	73
Cotton	75
Tobacco	80
Potatoes	83
Sweetpotatoes	87
Reliability of the estimates for selected crops—Continued.	
Tame hay	88
Flaxseed	92
Buckwheat	93
Field beans	95
Peanuts	96
Rice	97
Other minor crops	98
Dispersion of yield samples	99
Probable errors of the averages of yield samples	100
Comparison of yield estimates of the Department of Agriculture and yields derived from Census data	101
Wheat	117
Corn	120
Oats	122
Flaxseed	122
Cotton	124
Tobacco	126
General considerations in regard to comparisons of yield estimates	128
Estimates of yield per acre, 1866 to 1925	129
Size of sample	129
Representativeness	132
Bias	132
Conclusions	133
Literature cited	137

INTRODUCTION

Long-established theories in the field of economics are now being subjected to the searching light of quantitative analysis. The statistical approach is used to test theories derived by deductive reasoning as well as to form the basis of new inductive generalizations. Only in recent years have sufficient data been available for comprehensive statistical analysis. Practically all the publications of a statistical nature in this country have dealt either with the technic of analyzing quantitative data or with the results of such analysis when applied to a particular problem. Too little attention has been given to the problems involved in the collection and compilation of data and the making of estimates. A careful appraisal of the statistical data used in a given problem is fundamental if the conclusions based on the analysis of the data are to have validity.

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The tables appearing each year in the Yearbook of the Department of Agriculture contain two fundamentally different kinds of statistical data. First are those which result from enumeration of all items under a given category, such as the number of hogs slaughtered under Federal inspection, receipts of grain at primary markets, exports and imports of agricultural products, and the Federal census of agricultural production. Second, are estimates based on samples drawn from designated populations, such as the annual estimates of acreage, yield per acre, and production of various crops, number of livestock on farms, most of the market-price quotations, farm prices, farm wages, grain stocks on farms at specified dates, and agricultural income. Although the source of the material is pointed out in footnotes to the tables, many research workers, even some within the Department of Agriculture, fail to distinguish between the reliability of the different sources when drawing conclusions from the analysis of these statistics.

Any user of this large assortment of statistics would prefer data derived from enumerations rather than estimates based on sample data, provided that count be absolutely complete, or at least contain a uniform degree of incompleteness, throughout the entire series. It is conceivable that an estimate might be closer to the truth than an incomplete count or enumeration. The reliability of an estimate depends on several factors, including the homogeneity of the population from which the sample is drawn, the representativeness of the original sample data, freedom from bias, size of the sample, and the technical knowledge and common sense of the statistician making the estimate.

The research worker who uses the statistics compiled by the Department of Agriculture is entitled to know just how the data were gathered, and he should be given some basis for appraising their accuracy and reliability, whether they are results of enumeration or estimates based on sample data. Progress in the field of economics is being retarded at present because this type of essential information is not always available.

Statistics on agricultural production generally antedate those covering manufacturing and industry. The Sixth Federal Census, taken in 1840, contained items relating to agricultural production, but it was not until the Tenth Federal Census, in 1880, that both the acreage and the production of crops were enumerated. During the forties and fifties various agencies, including the Patent Office, trade journals, and newspapers, attempted to estimate production of the more important crops, such as cotton, wheat, corn, and oats, but the results were so unsatisfactory that when the office which eventually became the Department of Agriculture was organized in 1862 it was charged with the collection and compilation of agricultural statistics.

Official estimates of crop production must necessarily be both accurate and timely if they are to measure the annual supply of a given crop for the buyer and the seller, and thereby reduce the speculative fluctuations of the market price. The greatest accuracy could be obtained by means of a complete annual census or enumeration of the acreage, yield per acre, and production of each of the various crops. Such a census could not be taken until after the harvest was practically completed, and then it would require from

several months to a year or more to tabulate its returns and make them available. It would also be very expensive in comparison with the cost of developing a crop-reporting service.

Not only are accurate estimates of the production of crops required immediately following the completion of harvest, but buyers and sellers demand forecasts of production of the various crops prior to harvest. "They could not do without them. Private agencies will supply them, and the government as a neutral crop reporting agency can not avoid its responsibility by omitting them" (*15, p. 320*).[1] Methods of forecasting are being steadily improved. With cotton, for example, on which there is an accurate check on production, the December estimate of production for 1928 was 99.3 per cent of the final ginnings. In 1927 the December estimate was 98.7 per cent of the final ginnings. The production forecasts of September, October, and November, during 1929, were each within 1 per cent or less of the December estimate, and the December estimate was 100.6 per cent of the final ginnings.

Forecasts and estimates of crop production are necessarily based on sample data rather than on enumerations. During June each year thousands of farmers report to the Department of Agriculture the acreages of the various crops growing on their farms, both for the current season and the year previous. From this and other information the percentage change in the acreage of each crop is estimated by the Crop Reporting Board. This percentage change in acreage is applied to the estimate of acreage for the previous year to produce an estimate of the acreage for the current year for each of the various crops. The decennial or quinquennial Federal agricultural census enumeration, with some adjustments for incompleteness, furnishes the base or starting point for estimates of acreage.

During the growing season forecasts of the probable yield per acre are made on the basis of the "condition of the crop in per cent of normal," actually on appearance, as reported by the regular crop correspondents. The relationship of condition to final yield per acre as a basis of forecasting is supplemented by weather and yield relationships.

After the harvest of a given crop is completed in practically all States, estimates of production for the crop are made by multiplying the estimate of acreage of the crop remaining for harvest after abandonment is deducted by an estimate of yield per acre. In late September an extensive survey of the current year's acreage of all crops is made with the help of the rural mail carriers of the Post Office Department. Results of this survey, with other information, form the basis of the estimates of the acreage of the various crops remaining for harvest. The crop correspondents, both regular and special, report on the average yield per acre of the various crops in their locality, and these returns are used as a basis for the crop estimate board's estimates of yield per acre. The forecast of production for a given crop in a particular State is the product of the acreage estimate multiplied by the forecast of probable yield per acre.

Accurate estimates of production require that methods of estimating all component factors be accurate and reliable.[2]

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[1] Italic numbers in parentheses refer to Literature Cited, p. 137.

[2] The reliability and adequacy of the farm price estimates of the department have been considered in U. S. Department of Agriculture Bulletin 1480 (*14*).

In the field of crop estimating, as in any other specialized field of knowledge, it has been necessary to develop a technic applicable to the problems involved. Many of these problems are similar to those now being encountered in the more general field of quantitative analysis of economic data. The general principles of statistics, especially as related to sampling, have been of material assistance in understanding the technic developed through many years of experience in crop estimating and in suggesting improvements that have already proven their worth.

The general problem of determining the reliability and adequacy of estimates of crop production must be considered from the standpoint of two specific problems—the accuracy of estimates of acreage and accuracy of estimates of crop yields per acre. The statistical principles related to the methods of sampling used in estimating crop yields per acre are much less complex and are of more universal application in the general field of quantitative procedure than are those related to the estimating of acreage. This study will be limited to the specific problem of estimates of crop yields per acre. A study similar to this has been made in connection with estimates of acreage, and many of the improvements in method that were developed have been incorporated in the procedure of estimating the acreage of crops.

PURPOSE AND PROCEDURE

The primary purpose of this bulletin is to report the results of a critical investigation of the sources of current information, the character of the information received, and the methods used in preparing the official estimates of yield per acre of crops. This investigation has been conducted over a period of several years, has served as a basis for determining the reliability and adequacy of estimates of crop yields per acre, and has resulted in improvement and refinement of methods used in preparing such estimates.

The procedure followed in the study was to examine the data regularly available to the Department of Agriculture in the light of statistical principles, related to sampling, that had been tried and proven in other fields. In the course of this examination the data basic to many of the official estimates for principal crops in related States were reworked, and accepted measures of reliability were applied. Official estimates were compared with the yields indicated by the reports received, considered alone without correction by the board.

The results are presented in the following order: (1) Description of the nature and sources of reports from farmers; (2) treatment of sample data to meet practical and theoretical requirements; (3) detailed critical analysis of the data for typical States and years for important crops; (4) comparison of yield estimates of the Department of Agriculture with yields derived from the census data; and (5) an appraisal of the historical series.

The first part, which deals with a description of the phenomena and methods is treated in summary fashion in view of available materials on the general subject.

The second part of this study, which adapts available sampling principles to the immediate problem of estimating the yields of crops, has resulted in a classification of the factors that cause samples to be misleading and estimates to be inaccurate. These generalizations,

which are based on experience in the field of estimating crops and livestock, have a definite application in the general field of making estimates and drawing conclusions from sample data. Every constructive worker in economics and related social sciences is forced eventually to utilize sample data, whether he collects them himself or not.

The detailed analysis of the sample data for typical States and years for important crops has involved an immense amount of labor both in actual performance, and in checking the accuracy of the work. A large part of this labor has been done by the staff of field statisticians in the various States and other workers of the Division of Crop and Livestock Estimates, in connection with courses of instruction in sampling and general statistics conducted by the author during the last three years.

In the fourth phase of this study, the sample data and estimates of yield have been directly checked against the yields per acre derived from census data. This is an entirely separate approach to the problem of the reliability of yield estimates. The conclusions of this study are based, therefore, on the results obtained by using two different methods of investigating the same general problem and are considered more dependable than if either had been utilized alone.

The brief evaluation of the yield estimates as a historical series will be helpful in explaining year-to-year variations in the yield of a given crop in a certain State on the basis of the weather and economic factors involved.

Scientific workers and students, especially those in the field of the social sciences, who are making and interpreting surveys and samples of social and natural phenomena will be particularly interested in the principles and methods of sampling as they have been developed by the United States Department of Agriculture over a period of more than 60 years. To this group the first part of this bulletin to and including the discussion of the reliability of the estimates for winter wheat will have greater significance than the remainder. Others, however, may be interested in the reliability of the yield-per-acre estimates for one or more particular crop. It is suggested that they consider the section on winter wheat as a basis for comparison with the particular crop of their interest. Those interested only in the general reliability of yield estimates made by the department will find most of their questions answered in the summary.

SOURCES AND KINDS OF INFORMATION

PHENOMENA OF CROP YIELDS

The phenomenon that the Department of Agriculture is called upon to measure and to estimate is the average yield per acre of a given crop for the United States, for a State, and for some subdivision of the State, such as a county or group of counties. The estimate of yield per acre for a State is theoretically the total production of a given crop in that State divided by the total number of acres of that crop harvested.

Although the term "average yield per acre" implies that the actual production on an acre of ground is the unit of observation, experience teaches that the smallest unit in actual practice undoubtedly is the average yield per acre for a field. If a farmer is asked

how much corn he grows per acre on his farm, he is likely to say that on his 40-acre field on the river flat he produced 60 bushels to the acre and on his 20-acre field over on the hill, his average yield per acre was only 40 bushels. The production of a crop on a given field, divided by the area of that field, is about the smallest unit in which the farmer thinks of yield per acre. It is the rate of production per acre for any given area such as a field, several fields, or the locality.

Yields per acre of any given crop differ as between fields, between farms, between counties, between States, and between geographical areas. These differences result from difference in soils, cultural practices, seed selection, weather, farm management, and other factors. Since crop production is a natural phenomenon, it is reasonable to expect a fairly normal distribution of the observations if the samples are drawn from a reasonably homogeneous area.

Differences in soil fertility, topography, and climate are the fundamental causes of the variation in crop yields for the country as a whole. The Delta counties of Mississippi have on an average, much higher yields per acre of cotton than have the upland counties. The areas of high production per acre for the country as a whole are rather well determined and tend to be fairly homogeneous; areas on the margin of profitable production are less clearly defined geographically. Yields per acre not only differ, but so also do the geographic distribution and density of the acreage planted to a given crop. With the approach to the geographic margins of profitable production of a given crop, a smaller proportion of farm land is planted to that crop. In sampling for yields per acre of a crop it is necessary to consider not only geographic variations in yields but also geographic distribution of the acreage.

A political unit such as a State or county is not necessarily, and in fact is seldom, a homogeneous geographic district from the standpoint of either yield per acre or acreage distribution. If an approach to a normal distribution is to be secured in the observations of the sample of crop yields, a State should be divided into districts having natural conditions as nearly uniform as possible. In actual practice a State is usually divided into nine crop-reporting districts of about equal extent, on the assumption that the variation both in yields per acre and in the distribution of the acreage is greater over the entire State than within one of these districts. To the extent that this assumption holds true, the crop-reporting district is more homogeneous than the State as a whole. Homogeneity within the districts has been materially increased, in the case of several States, by giving more careful attention to natural geographic and climatic factors and the distribution of the acreage of the important crops when selecting the counties that are to be included within each district.

There are 41 State offices at present. There is one field office for the New England States, one for Maryland and Delaware, and one for Nevada and Utah. The two lists of crop correspondents, township and field aids, have now been merged in several States, including the New England States, New York, Pennsylvania, New Jersey, Maryland, Delaware, Virginia, West Virginia, Florida, and California. The combined list of crop correspondents reports to the field offices in these States. Generally speaking, these are States in which the crops of general speculative interest, such as wheat, corn, oats, and cotton, are relatively unimportant, or in which the agriculture is so

highly specialized that a sample has little significance unless interpreted by one familiar with the agricultural details of the State. It is deemed advisable, however, to continue this dual system of crop correspondents, in most important agricultural States, especially in those with highly speculative crops, as it insures that sample data will be available for the Crop Reporting Board. Reports from the State officers are sometimes lost or fail to reach the board by the morning of the day the report is released.

In some of the important grain States the returns from the regular crop correspondents of the department have been supplemented by special questionnaires to country mill and elavator managers, each of whom is asked to estimate the yield per acre for the more important grain crops in his locality.

In many States an additional "judgment inquiry" is sent out in the late fall to farmers who are not regular crop correspondents of the department. The returns from these inquiries, taken later in the season, supplement the regular returns and are especially helpful when estimates of yields are made on less than a State basis.

THE LISTS OF REPORTERS

The Department of Agriculture now maintains two lists of crop correspondents. Both lists are recruited from among farmers who are willing to serve without compensation and who are selected with the idea of having on each list at least one reporter from each agricultural township in the United States. The township list, which reports to Washington, has usually consisted of about 30,000 or more farmers. There are at present about 46,000 correspondents on the field-aid list, which reports to the field statisticians in each State. For any regular monthly report about 50 per cent of the correspondents return the questionnaires. The township list was first established in 1896 and the field-aid list in 1914, when the field force of the Bureau of Crop Estimates was reorganized. In 1925, the list of county correspondents was merged with the township list. The county correspondent was expected to provide himself with from three to five assistants living in different parts of the county, who reported to him the yields in their localities, while he in turn, made an estimate for the entire county.

JUDGMENT INQUIRIES

From the beginning in 1862 to 1930 the official estimates of crop yields per acre have been based primarily on what is called the judgment inquiry, in which the unit of observation for a given crop is the crop reporter's estimate of the average yield per acre in his locality. From 1862, when the county reporters were organized, until 1896, when the township list of crop correspondents was begun, the unit of observation was theoretically the average yield per acre for an entire county. It is obvious that, as a matter of fact, the average yield for the locality with which the reporter is familiar has always been the unit of observation.

In the generally used judgment inquiry of the department the crop reporter is asked to make an estimate of the average yield for his locality which, theoretically, would be the total production divided by the total acreage therein. In actual practice the crop reporter presumably starts with the knowledge of the average yield per acre on his own farm; then through contacts with other farmers, he obtains

information concerning the average yields on other farms in his locality. Many reporters undoubtedly not only consider the yields obtained on farms with which they are familiar, but go even further and make an allowance for the poor appearance of some outlying farms for which they do not have accurate information. No effort is made to limit the locality that the crop reporter represents. It is possible that the influence of the higher yields on the reporter's own farm tends to result, in years of very low yields, in an estimate that is above the true situation.

After conversations with many crop reporters in Iowa, the writer is under the impression that most reporters do make an allowance for the low yields as well as for the high yields obtained in their immediate neighborhoods. Most of the reporters are better-than-average farmers and although they generally obtain better-than-average yields on their own farms, they do tend to discount their own yields in arriving at an estimate for their locality.

From 1883 to 1914, the returns from these voluntary crop correspondents, who reported directly to the department in Washington, were supplemented by the observations and estimates made by part-time State statistical agents, each of whom had a small group of crop correspondents. From about 1900 to 1914, full-time regional field agents were employed to travel continuously during the growing season and immediately after harvest over a territory comprising several States. They observed the condition and appearance of the growing crops and estimated the average yield per acre for each of their States on the basis of their observations, reports from a limited list of crop correspondents, and other information secured from operators of mills and elevators and informed persons with whom they came in contact during travel.

During the last few days of the month both lists of reporters receive a questionnaire which includes various items such as the condition in per cent of normal of the growing crop, yield per acre of different crops shortly after harvest, and miscellaneous questions on farm labor, farm wages, poultry and milk production, etc. The "probable yield" as well as the condition of wheat and rye is included on the June questionnaire for reporters in the Southern States. In July the questionnaire asks for the harvested yield of wheat and rye in the Southern States and the probable yield in the Northern States. The probable yield for the more important crops is requested about harvest time, and harvested yield is requested a month later, some allowance being made for the advancement of the season in the Southern and the Northern States. The October inquiry (fig. 1) includes the harvested yield of the spring-sown grains and the probable yields of corn and potatoes. The last inquiry on yield per acre for the season has been as of November 1; such late-harvested crops as corn, potatoes, and buckwheat were included. Beginning with 1928 in the Northern States the yield inquiry for corn was repeated on December 1, and this practice will be continued in the future. Early each year there is an announcement of the list of crop reporting dates for the year,[3] which shows what is to be published in connection with each crop report throughout the year.

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[3] UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF AGRICULTURAL ECONOMICS. CROP REPORTING DATES FOR 1931 AND WHAT WILL BE. U. S. Dept. Agr., Bur. Agr. Econ. Press Release. [1] p. January 31, 1931. [Mimeographed.]

REPORTS FOR INDIVIDUAL FARMS

In addition to these judgment inquiries, both regular crop reporters and other farmers are asked to report on the acreage and production of the crops on their own farms. From these reports a yield-per-acre

[C. E. 2-2937] "N"

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF AGRICULTURAL ECONOMICS—DIVISION OF CROP AND LIVESTOCK ESTIMATES
WASHINGTON, D. C.

[OCTOBER, 1929]

OCTOBER CROP SCHEDULE

Name.....
Post Office..... R. D. No.....
County in which I live.....
State.....

This schedule is to be mailed by October 1, 1929. Report ONLY on such crops named as are grown in your locality; report for that part of the country about you which comes under your personal observation, or with which you are familiar. Please read carefully the instructions below before making report.

INSTRUCTIONS TO REPORTERS

1 The **condition of the crops** on the date indicated for making the schedule is **not** in comparison with a condition at any former period, but with a **normal** condition of growth and vitality such as would be expected at this time in a crop starting out under favorable conditions and not subjected afterwards to unfavorable weather, insect pests, or other injurious agencies. If condition is asked for any crop that has already been harvested, give condition at time of harvest.

2 In **estimating condition of crops** in comparison with a normal condition of growth and vitality giving promise of a full yield per acre (100 the basis, if nine-tenths of a full normally yield per acre are indicated by the present condition, the answer should be filled in as 90, if one-tenth, or 10 per cent, more than a normal yield per acre is indicated, the answer should be reported as 110, etc.

3 **Quality** should be reported on the basis of 100 representing a high medium grade; **production**, on the basis of 100 representing a production normally or usually raised in a favorable season (see item 35).

4 Included under "**All tame hay**" all cultivated grasses and legumes, alone or mixed, such as timothy, clover, alfalfa, millet, Johnson grass, etc., and all grains, including field beans and peas cut green and cured for hay, but exclude wild, salt, or prairie grasses, also exclude coarse forage crops, such as corn, sorghum, kafir, etc. (See items 23 and 24.)

5

SYMBOLS TO BE USED

Use cross (X) when crop is not grown at all or is grown to so small an extent as not to be worth reporting. Use dash (—) when information is not sufficient for an estimate. Write in the word "**Failure**" to indicate an entire failure. Use cipher (0) only when no grain remains on farms on October 1, 1929.

THE REPORT

6 Use the schedule only for the report. Make all other communications on a separate sheet of paper, which may be inclosed in envelope with schedule, but each sheet of paper should have your name, **county**, State, and post office address written plainly thereon.

7 It is important that reporters mail their reports by the date indicated, as the report of the Department can not be delayed for those which are not promptly returned.

Respectfully,

Chairman, Crop Reporting Board.

RETURN SCHEDULE EVEN THOUGH YOU CAN REPORT FOR ONLY ONE OR TWO ITEMS

Corn		Durum wheat		Other spring wheat		Oats		Barley		Buckwheat	Flax for seed		Sorghum cane (for sirup)	Potatoes		
(1) Condition	(2) Probable yield per acre this year	(3) Yield per acre this year	(4) Quality	(5) Yield per acre this year	(6) Quality	(7) Yield per acre this year	(8) Quality	(9) Yield per acre this year	(10) Quality	(11) Condition at time of harvest	(12) Condition at time of harvest	(13) Probable yield per acre this year	(14) Condition	(15) Condition	(16) Probable yield per acre this year	
Per cent	Bu. of 70 lbs. in ear	Bushels of 60 lbs.	Per cent	Bushels of 60 lbs.	Per cent	Bushels of 56 lbs.	Per cent	Bushels of 48 lbs.	Per cent	Per cent	Per cent	Bushels of 56 lbs.	Per cent	Per cent	Bush ls of 60 lbs	

Sweet potatoes and yams		Tobacco		Soy beans for beans	Cowpeas for peas	Hay (all tame) (See instruction 4)		Alfalfa hay	Alfalfa seed	Clover hay (red and alsike)	Red and alsike clover for seed	Millet and Sudan	Soy bean and cowpea hay	Other hay (red top, orchard grass, mixed hay on old meadows)	Timothy seed	Pasture
(17) Condition	(18) Probable yield per acre this year	(19) Condition at time of harvest	(20) Probable yield per acre this year	(21) Condition	(22) Condition	(23) Yield per acre this year	(24) Quality	(25) Yield per acre (all cuttings combined) this year	(26) Condition at time of harvest	(27) Yield per acre (all cuttings combined) this year	(28) Condition at time of harvest	(29) Yield per acre this year	(30) Yield per acre this year	(31) Yield per acre this year	(32) Condition at time of harvest	(33) Condition
Per cent	Bushels of 60 lbs	Per cent	Pounds	Per cent	Per cent	Tons of 2,000 lbs.	Per cent	Tons of 2,000 lbs.	Per cent	Tons of 2,000 lbs.	Per cent	Tons of 2,000 lbs.	Tons of 2,000 lbs.	Tons of 2,000 lbs.	Per cent	Per cent

Apples		Peaches		Pears	Grapes	Wheat		Oats		Rye		Corn		Milk production (Report for your own farm)				
(34) Condition (per cent of a full crop)	(35) Production this year (per cent of a full crop)	(36) Quality	(37) Condition (per cent of a full crop)	(38) Condition (per cent of a full crop)	(39) Total number of bushels of wheat produced on the farm in 1929	(40) Number of bushels of wheat on hand Oct. 1, 1929	(41) Total number of bushels of oats produced on the farm in 1929	(42) Number of bushels of oats on hand Oct. 1, 1929	(43) Total number of bushels of rye produced on this farm in 1929	(44) Number of bushels of rye on hand Oct. 1, 1929	(45) Total number of bushels of corn produced on the farm in 1929, last year	(46) Number of bushels of old corn on hand Oct. 1, 1929	(47) Number of cows milked on your farm yesterday	(48) Number of all milk cows in your herd yesterday (both dry and in milk)	(49) Total production of milk by your herd yesterday (Report in either pounds or gallons)		(50)
Per cent	Per cent	Per cent	Per cent	Per cent	Bu. of 60 pounds	Bu. of 60 pounds	Bu. of 32 pounds	Bu. of 32 pounds	Bu. of 56 pounds	Bu. of 56 pounds	Bu. of 70 lbs. in ear	Bu. of 70 lbs. in ear	Number	Number	Pounds	Gallons

Egg production (Report for your own farm)				Turkeys	Farms in reporter's school district				Farm labor		
(51) Number of hens, 6 months old and over, on farm at present time	(52) Number of eggs produced by your flock yesterday	(53) Number of pullets not yet of laying age, but being saved for layers	(54) Number of chicks and young chickens other than pullets being saved for layers on hand yesterday	(55) Number of turkeys 6 months old and over on your farm	Approximate number of farms in your school district		Of these how many were NOT visited		(58) Number of persons working on this farm (Do not include household workers)		
					(56) Total number	(57)	(59) This year (1929)	(60) Last year (1928)	(60) Family Labor (including operator)	(61) Hired help, including months, or day and piecework basis	
Number	Number	Number	Number	Number	1930	1929	Number	Number	Number on farm Oct. 1	Number on farm Oct. 1	

USE BACK OF SCHEDULE FOR COMMENTS ON UNUSUAL CONDITIONS

U. S. GOVERNMENT PRINTING OFFICE 1929

FIGURE 1.—Typical monthly schedule or questionnaire. The monthly questionnaires sent to crop reporters differ with the nature of the information sought as the season progresses. In October the inquiry chiefly concerns the yields of crops. For those crops not harvested prior to October 1, the reporter necessarily gives his idea of the "probable yield." In some of the States and for those crops the harvest of which has been virtually completed the report is on "yield per acre this year"

estimate can be derived by dividing production by acreage. This is known as an "individual farm" inquiry. Since the crop correspondents are generally better-than-average farmers, the individual-farm returns usually show a higher average yield per acre than do the judg-

ment inquiries. These individual-farm inquiries are made usually in the late fall after harvest is over for practically all crops except corn.

In years of generally good yields the spread between the yield per acre on the farms of crop correspondents and the average for all farms in the State is probably not as great as in years of low average yields because the crop yields of the better farmers are not so likely to be affected by adverse conditions as are the yields on either marginal land or on the farms of less skillful farmers. The individual-farm inquiry was first developed and used as a check on the judgment sample during the eighties, but it has not been in continuous use, largely because of its obvious limitations.

The yields derived from the individual-farm sample may be used in a relative sense, when their limitations are understood, as indicating the relative change in yields from one year to the next; they are especially helpful with winter wheat in years of heavy acreage abandonment, serving as a means of estimating production independently of yield and acreage estimates. In 1928, for example, there was heavy abandonment of winter wheat in the eastern Corn Belt States, and considerable land on which winter wheat had been destroyed was allowed to remain unplowed because of the excellent stand of new grass seeding. Many fields were allowed to remain without being plowed up for some other crop, but were only partly harvested. This situation made extremely difficult the determination of both the actual acreage harvested and the yield per acre of harvested acreage. The individual-farm production schedules were especially helpful in supplementing the returns from the regular judgment inquiries.

CENSUS ENUMERATIONS

In the years for which a Federal census is taken, the census is available as a third source of information concerning the yield per acre of the various crops. These yields are derived from the census of acreage and production through dividing the latter by the former. Unfortunately the Federal census is not taken until so many months after harvest that this information is sometimes not available for a year or two after the specified harvest and can be used only as a basis for revising the yield estimates of the crop year to which the census applies. Should only the yields in the census year be revised on the basis of this information, which is available every 5 or 10 years, these estimates for the census year would not be comparable with the estimates for the intervening years.

It would appear on first thought that these yields as derived from the census data would serve as an excellent check on the accuracy of the estimates of yields made by the Department of Agriculture, and reveal the measure of the discrepancy between the results of an enumeration and estimates based on sample data. Subsequent investigation will show that several circumstances concerning the enumeration of acreage and production must be taken into consideration when closely comparing yields as derived from the census data with either the estimates of yield per acre or the averages of original sample data secured from the crop correspondents of the department.

COMMERCIAL CHECKS

The department has been obtaining commercial checks on production, such as figures showing cotton ginnings, car-lot shipments of fruit and vegetables, shipments and mill-door receipts of grain and flax in the spring-wheat States, and auction sales, which are useful as indicators of probable production during harvest and as a basis for estimating production after harvest. The field or State statistician gathers his summer information concerning acreage changes, production, yield per acre, and marketings, from farmers, county agents, elevator men, bankers, and others, for both the current and previous year.

PREPARATION OF THE ESTIMATES

The returns from township correspondents are tabulated and edited in the central office in Washington. The returns from the field-aid reporters, and from the combined list of correspondents in those States in which the two lists have been merged, are tabulated and edited in the respective State field offices.

The returned questionnaires (fig. 1) are usually entered on large sheets, by counties or by crop-reporting districts. This organization of the observations on a county basis is of material assistance in editing and checking and makes possible the computation of averages by counties. After the returns have been listed and carefully edited, averages are computed by counties in the field offices, and by crop-reporting districts in the central office in Washington. These averages of crop-reporting-district data are then weighted by acreage weights for the current year's crop to secure a weighted average yield per acre for the entire State. The unweighted or straight average (arithmetic mean) of all reports for the State is also calculated.

At harvest time the field statistician in each State carefully summarizes the sample data that he has received from his field-aid reporters and from such special correspondents as mill and elevator managers and cotton ginners. From observations and contacts made during travel over his State, and in the light of many years of experience in that State, he considers the representativeness of the sample, its size, and the possibility of bias, and arrives at an estimate of the yield per acre of a given crop for the State. This estimate usually does not differ materially from the weighted average of the returns from the field aids. The estimates of the field statistician, and the statement of the district and State averages from his crop correspondents are mailed to the Crop Reporting Board in Washington. Comments concerning the weather and other pertinent factors accompany these data.

These reports from the field statisticians to the board are divided into two classes, the A reports which deal with corn, wheat, and oats, and the B reports which include all other crops except cotton. The reports on corn, wheat, and oats, from States in which these crops are of very minor importance from a national standpoint, are included with B reports. The reports on cotton are handled separately from all other reports and are released a day or two prior to the general report, which by law must be issued not later than the 10th of the month. The B reports are mailed directly to the board prior to the mailing of the A reports, which are sent directly in a specially marked A envelope to the Secretary of Agriculture. The A envelopes are

placed immediately in a safe where they remain locked up until the morning of the day the crop report is released, when they are opened in the board room.

The Crop Reporting Board makes its estimates of the A crops behind locked doors and screened windows, and under guard, on the day of the release of the general crop report. The cotton report is handled in the same manner throughout as is the report on the A crops. At a specified minute copies of the crop report are laid face down beside telephone or telegraph instruments through which newspaper reporters assembled for the purpose may, at the stroke of a bell, transmit the details. Through relays, the report is available almost instantaneously at any point in the world. In making this report the Crop Reporting Board considers the sample data from various sources, other information, and the estimates submitted by the field statisticians, and arrives at an estimate of yield per acre by States, which is applied to the current estimates of acreage to obtain an estimate of production by States and for the country as a whole.

In December, when the final estimates of acreage, yield, and production for the current year are made, the Crop Reporting Board reconsiders all information obtained since the harvesting of the various crops, that concerns the yield per acre. If a revision of the yield per acre is apparently justified, such a revision may then be made in connection with the final estimates for the year. The following year, in connection with the July report or the December report, further revisions may be made if convincing evidence of need has appeared in the meantime. The final check of car-lot shipments, mill-door receipts, ginnings, etc., sometimes justifies these later revisions of yield as well as of acreage.

ADEQUACY OF SAMPLE DATA

THE PROBLEM

Present-day economists are making use of statistical information to a greater extent than ever before in the history of economic thought. Research workers are compelled to base generalizations upon sample data of one kind or another. Even when statistical series that have been completely enumerated over a period of years are used as a basis for relationship studies or correlation analysis, the data for the years included in the study are a sample of only a few years taken from a universe of all years or an infinity of time. There are always the questions as to whether the results secured for the limited period under observation will continue to be applicable in future years, and whether the generalizations that apply to the sample really apply to cases not included in the sample. The statistician's basis for assuming that a generalization concerning the average yield per acre of a crop from sample data will apply to the cases not included in the sample must be logically developed.

The ordinary methods of inductive reasoning are used, basing the logical processes upon statistical data. The whole practical problem of statistics centers on the validity of the reasoning process; on the validity of the assumptions upon which this type of inductive reasoning, known as statistical induction, is based. The fundamental assumptions that underlie this type of inductive reasoning may be briefly stated, but they must be held constantly in mind.

(1) There is the general assumption of the orderliness and uniformity of nature, or that there is some finite degree of variation in nature. (2) A random sample with all observations free from bias is usually assumed. (3) The conclusions from sample data can not be absolute and must consequently be expressed in terms of probability, which, however, can be given assignable limits. Any development or adaptation of the general theory of sampling must center about these fundamental premises to statistical inductive reasoning. In actual practice it is soon discovered that a random sample is very difficult to obtain and may be actually quite misleading, and that the observations in the sample are subject to both wide errors of observation and bias.

Can a sample be so drawn or so handled that it will reflect the situation of the large group or universe of inquiry from which it is drawn? This is fundamentally a problem in "sampling" in its broadest and most practical application. It involves a comprehensive statistical description of the sample data upon which the estimates of yield per acre primarily depend, and a careful consideration of the problem of statistical induction which is involved when an estimate is made largely on the basis of sample data. It is always difficult in practice to differentiate sharply between these fundamental distinctions inherent in the theory of statistics. As Keynes says (*9, p. 377*):

> The first function of the theory of statistics is purely *descriptive*. It devises numerical and diagrammatic methods by which certain salient characteristics of large groups of phenomena can be briefly described. * * * The second function of the theory is *inductive*. It seeks to extend its description of certain characteristics of observed events to the corresponding characteristics of other events which have not been observed. This part of the subject may be called the Theory of Statistical Inference.

Later Keynes points out that the more complicated and technical the preliminary statistical investigation becomes, the more inclined is the statistician to mistake the statistical description for an inductive generalization. Inductive reasoning tells us that on the basis of certain evidence a certain construction is reasonable, not that it is true. Induction depends upon experience for its validity.

Theoretically the making of an estimate of crop yields involves, (1) the collecting of sample data concerning yields per acre. These data are tabulated and edited, and an average (which is one of the most important characteristics of a sample) is computed. (2) The making of an estimate of a particular crop for a given State involves statistical inference. The statistician must take the step from his sample to the universe of inquiry, that is, in this case, from the average yield per acre for a given crop as shown by his sample to an estimate of yield for the State as a whole. The reliability of the estimate will depend not only upon the reliability and adequacy of the basic sample data, but also upon the statistician's appreciation of the assumptions involved and his interpretation of the indications from the sample.

The statistician does not willingly accept the average of the sample and use it as an estimate of the yield per acre for the State unless he is satisfied (1) that the universe from which the sample was drawn is reasonably homogeneous, (2) that the sample is fully representative of the State as a whole, (3) that the individual observations are free from bias or cumulative error of any kind, and (4) that the sample itself was sufficiently large to insure a high degree of "precision" or stability in the average obtained. He may also be influenced by

such objective information as cotton ginnings to date and car-lot shipments, which indicates to some extent the change in production from the previous year and by his own observation and contacts in evaluating the sample and in drawing inferences when generalizing from the sample to the estimate of the average yield for the entire State. A great deal of the information and experience needed for the most intelligent interpretation of the sample can be obtained from a careful statistical analysis of similar samples collected in the same manner from much the same list of crop correspondents in previous years. These samples can be tested for various kinds of representativeness, for the influence of size of sample, and even for bias, provided check data are available. This systematic analysis of several previously obtained samples, in combination with a full appreciation of the current situation, forms an excellent basis for properly evaluating the sample data and consequently insures a high degree of accuracy in the estimates themselves.

It is possible to select a sample that will reflect the situation of the large group from which it was drawn. The requirements change with the objectives or the purposes for which the results of the sample are to be used. Consequently one of the first considerations in obtaining a sample of any kind is to determine the particular objective that is sought. Of the four general objectives of sampling in the field of agricultural economics, as outlined by the advisory committee on research methods of the Social Science Research Council,[4] two seem to apply most definitely to the sampling of crop yields per acre.

The first is to obtain an accurate description of conditions existing in a given universe of inquiry. Ideally the sample should be a miniature or replica of the universe being sampled.

The second objective is to obtain a measure of the change in conditions taking place from time to time rather than an exact measure of conditions existing at any one time. The absolute level shown by the average of a sample may be too high, but the change shown by successive samples from month to month, or year to year, may accurately represent the change taking place in the universe of inquiry. Constant bias or constant lack of representativeness is eliminated when data from two samples are used relatively. Obviously a sample which would be a miniature of the whole, taken from time to time would also reflect accurately the change taking place in the universe of inquiry.

In sampling for crop yields, the purpose of all the judgment inquiries is to realize the first objective—a miniature or replica of the universe of inquiry. Each observation represents the reporter's judgment concerning yields in his locality. A sample is wanted that will give the true average yield for the State as a whole. The estimate of crop yield per acre is used in an absolute sense when it is multiplied by the estimate of acreage to obtain an estimate of production for a given crop. The requirements are much more rigid when a sample is to be used in an absolute sense, than if the objective is only to measure change—the second objective.

With the individual-farm sample, in which a derived yield per acre is obtained by dividing the production of a crop by the acreage

[4] SOCIAL SCIENCE RESEARCH COUNCIL, ADVISORY COMMITTEE ON SOCIAL AND ECONOMIC RESEARCH IN AGRICULTURE. RESEARCH METHOD AND PROCEDURE IN AGRICULTURAL ECONOMICS. v. 1, 196 p. 1928. [Mimeographed.]

on which it is grown for the farms in the sample, the purpose is primarily to measure change in conditions, and an absolute replica of the universe of inquiry is not required. Comparability between the two successive samples is essential if they are to be used in a relative sense. Complete comparability as to location and persons represented in the samples for two successive years, can be secured only when the returns from identical farmers are compared. Not only may higher yields be expected from the farms represented in the sample than from all farms in the State, but it may be expected that this spread will not be constant from one year to the next. This spread probably is smaller in years of high yields than in years of low yields. If it could be assumed that the necessary correction factor, which is needed to convert the yields from the sample into average yields for the State, would remain constant from one year to the next, then the two samples could be used in a relative sense, to indicate change.

There is the further difficulty of finding a satisfactory base from which to depart or to apply the indicated change, when the two samples are used in a relative sense. When last year's estimate of final yields is the result of other and better samples or better check data, then a relative indication of change in yield can be utilized with greater confidence. The individual-farm sample is at best only a check on the judgment inquiry and serves as a second line of defense when unusual conditions arise and the evidence is conflicting.

REPRESENTATIVENESS OF YIELD SAMPLES

In using the judgment-inquiry sample with the objective of obtaining a replica of the universe of inquiry, so that the average obtained from it may be used in an absolute sense, the sample must be thoroughly representative of the entire population from which it was drawn. If the individual-farm sample is used, in a relative sense, with the objective of measuring changes in the population by being applied to some base year and carried along from year to year, then the problem is not so much one of obtaining fully representative samples as of obtaining comparative representativeness as between the samples that are to be compared. In this case what is wanted is successive samples from year to year which, taken collectively, will be representative of the change taking place in the population of the universe from which they are drawn.

How to obtain a representative sample in the realm of living things, as of the yield per acre of various plants, is fundamentally a biological problem. The individual observation in the judgment inquiry is based on the crop reporter's locality; in the individual farm-yield inquiry it is based on his own farm. Evidently it is necessary that the sample contain observations from the full range of possible yields either by localities or by farms for a given crop. All known differentiations of the universe from which the sample is drawn should be given consideration, and provision should be made for their inclusion within the sample and in so far as possible in proportion to their occurrence in that universe.

Some measure of the geographic representativeness of a sample can be obtained from a map that shows in detail the local topography, geography, soils, etc., of the points at which the observations were obtained. On both the township and field-aid lists the reporters are

distributed by townships, and it is possible to ascertain the townships not represented in the sample.

The importance of geographic representativeness depends on the extent of local differentiation in crop yields. If a county is made up of townships that differ considerably as to topography, soil fertility, and distance to shipping points, it is extremely important to have a report from each township in order to obtain a sample that will be representative of the county. On the other hand, if there is as great a range of yields within the township as over the county it is not necessary to be so particular concerning the distribution of reports by townships. The same reasoning would apply to counties within a crop-reporting district or in the State as a whole. Unless there is geographic differentiation in the universe of inquiry, a sample from one section is likely to show about the same yield as that from another.

When a county comprises two distinct types of soil, varying greatly in fertility, as may happen in any State in which there are broad rich bottom lands and less fertile uplands, it is of the utmost importance to have the sample include observations from localities on both types of soil and to obtain the observations in about the same proportion as the acreage of a given crop in these two localities. If a crop is grown on both irrigated and dry land in the same county or township it is necessary to consider the low, dry-land yields separately from the higher yields obtained on the irrigated lands. This differentiation is so extreme as actually to result in two different universes. If the observations from both dry-land and irrigated localities are handled as one sample it will be found that the observations arrange themselves into two distinct modal groups. Consequently there is no tendency toward a piling up of the observations at some central point, which is essential if the average, as computed, is to have statistical significance. A weighted average for the State can be obtained by using estimates of the acreage of the crop grown under irrigation and of the acreage grown on dry land as weights. This method was used in all the far Western States for the first time in 1929.

The crop-reporting districts (fig. 2) do tend to group the counties into districts that may differ considerably in the factors that influence yields per acre of a given crop. A number of State statisticians, have effected improvement in handling their sample data by regrouping the counties into more homogeneous crop-reporting districts than were obtained under the original rigid system of nine districts per State.[5]

It would be ideal if the sample could be selected in such a way that the number of reports would be proportional to the acreage of the crop, township by township within the county, and county by county within the State. The present system of distributing the reporters by townships tends to bring this about. The representativeness of the sample is further improved by the method of weighting the average yield obtained in each crop-reporting district by the acreage of that crop in that district, thus obtaining a weighted average yield for the State. The closeness with which the unweighted or straight average (arithmetic mean of all the reports) checks with the weighted average for a State indicates whether or not the sample is distributed as between crop-reporting districts in about the same proportion as the crop.

[5] The original nine districts were selected from the grouping of counties made by the Post Office Department which divides a State into nine districts—northwestern district, north-central, northeastern, west-central, central, east-central, southwestern, south-central, and southeastern.

Under some conditions this method of weighting effects marked improvement in representativeness, as in the case of cotton yields in Mississippi, where it is much more difficult to obtain reports from the

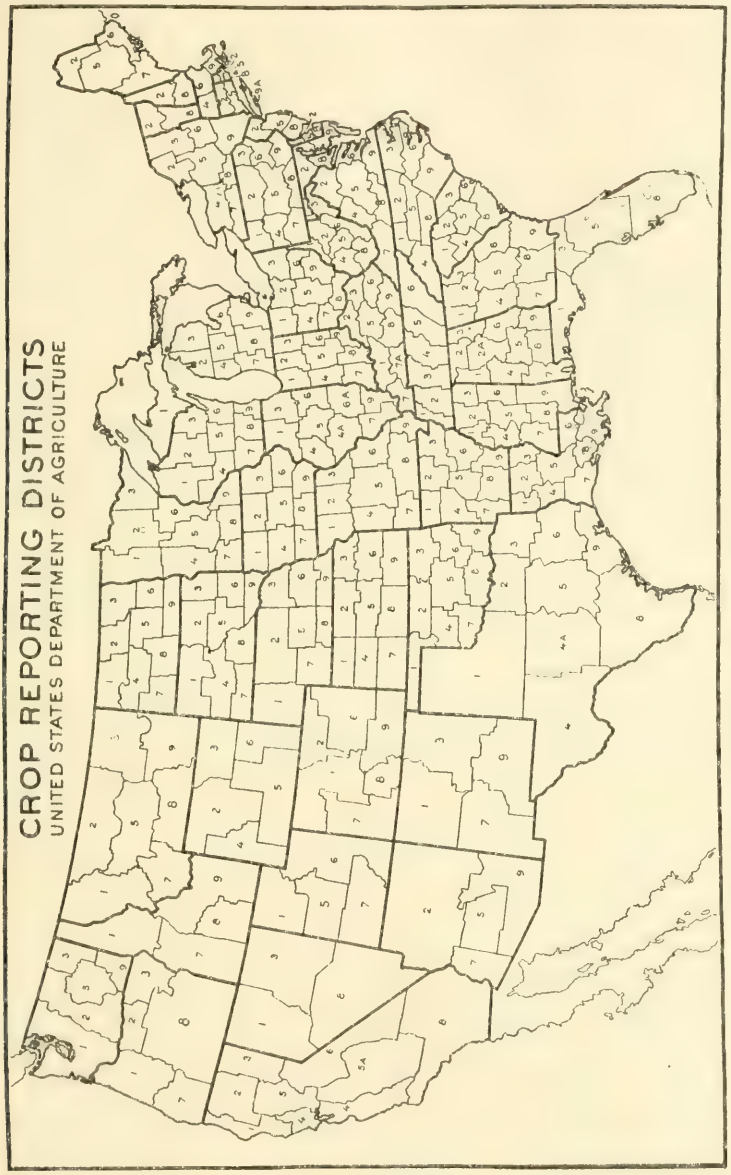

FIGURE 2.—Districting of States for crop-reporting purposes, is a modification of the system used by the Post Office Department in handling the mails. The district boundaries follow county lines and include those contiguous counties which together make up the most homogeneous agricultural producing areas possible under the limitations of location. Shifts in the boundaries have been made from time to time, especially in the Western States. This map shows the present lines

large plantations in the Delta counties than from the farms in the much lower yielding counties on the upland. Weighting a crop by irrigated and dry-land acreage materially improves the representativeness of the yield-per-acre sample.

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With highly localized crops, especially with fruits, commercial vegetables, and certain minor crops (such as potatoes, beans, peanuts, or tobacco in certain States), it is necessary to average and weight by counties; with a crop like beans it may be necessary to weight by varieties or types as well as by counties, in order to obtain a sample that is representative of the universe of inquiry. From the standpoint of geographic representativeness it is of the utmost importance that the State statistician be thoroughly familiar with the agriculture of his State in order that he may be in better position to evaluate the representativeness of his sample data. His travel over his State fits him to appraise reports that are not reasonable for a given locality.

Judgment inquiries require a sample selected in such a way that the reporting localities will represent the county, district, or State. So far as the representativeness of the crop reporters estimate for his locality is concerned, there is little opportunity to test the sample. Individual differences in yield exist as between fields on the same farm and farms in the locality. With this type of inquiry it is necessary to rely solely on the crop reporter's judgment concerning his locality, trusting that errors in all the judgment estimates may be compensating when the sample is of sufficient size. It is also possible that what is later designated in this study as "bias," in the observations themselves, is in fact due in part to the inability of the crop reporter under certain conditions to make an estimate that is truly representative of his locality.

With the judgment samples of yield per acre it is necessary to assume that (1) the reporter's estimate is representative of his locality, (2) the localities from which reports are received, are also representative, (3) the localities from which estimates are received do not overlap sufficiently to give undue weight to any one section of the State, and (4) the observations in the sample as reported are distributed proportionately to the acreage of the crop being sampled both within the county and in each crop-reporting district. Weighting yield-per-acre sample data of the major crops by counties changes the weighted average for the State so little from what it is when weighted by crop-reporting districts that the additional labor usually is not justified. With minor crops grown largely in certain counties (such as rye in Wisconsin and potatoes in many States) weighting on a county basis is necessary in order to obtain a representative sample.

With the individual-farm sample of yield the problem of representativeness applies to the farm as a unit and hence becomes a much more complicated problem than in the case of the judgment reports for whole localities. Not only is geographic representativeness just as fundamental as with the judgment inquiry, but there is the additional problem of selecting farms that are really representative of the different farms and farmers found in a county, district, or State.

When the individual farm is taken as the unit of observation, prior experience with agriculture suggests that there are many possible sources of differentiation. Yields may be higher on owner-operated than on tenant-operated farms, on small farms intensively operated than on large extensive farms, on farms where livestock is highly important than on farms where cash crops are grown. Better yields might also be expected on the farms of the more intelligent and public-spirited farmers such as those who are willing to serve as voluntary crop reporters. If weighting the sample by counties or crop-reporting

districts improves its geographic representativeness, it is equally logical to divide the sample on the basis of other well-known differentiations (such as size of farms, method of farm operation, etc.) that may be associated with yield per acre. Averages can be computed for these subdivisions of the sample and weighted by the importance of the crop in each subdivision to obtain a weighted average either for the crop-reporting districts or for the State.

This division of the sample into subdistricts is called "stratification." To insure comparability between the averages of two samples made up of individual farms taken at different times and used as relatives to indicate change in the universe of inquiry from one inquiry to the other, it is important that the sample be stratified (on the basis of any factor that may be related to the yield per acre, such as size of farm,) and that the same weights be used in computing the average for each of the two samples. If there is a relationship between size of farm and yields per acre the sample should be weighted on the basis of size of farm. This is especially true with individual-farm reports on acreage used in a relative sense. The use of a relative indication from two samples obtained from the same farmers for both years insures comparability without the necessity of stratification. The interpretation of a relative indication of change from two samples that are comparable depends on the statistician's judgment concerning how well the sample reflects the change that has actually taken place for the State as a whole.

This is a somewhat different problem from the one presented by a definite shift in the geographic distribution of the crop. In case of such a shift it would be necessary to use new weightings in order to obtain an accurate estimate of yield for the whole area under consideration.

METHODS OF SELECTING A REPRESENTATIVE SAMPLE

The question of representativeness is of vital importance in sampling. Pearl (*12*) in considering the geographic selection of observations in sampling says:

> The whole universe dealt with covers a certain area. To get a representative sample it will, therefore, be necessary to lay down over the whole area an imaginary network, in which all the meshes are of equal and not too large area, and then draw a sample relative to the other differentiations from within each mesh.

The selection of a reporter from each township for the township list of crop correspondents and another for the field-aid list is practically what Pearl suggests doing. In most statements concerning the selection of a sample that will be representative of the universe of inquiry great emphasis is placed on obtaining a perfectly random sample. In fact, any departure from random selection is presumed to result in a sample that would be useless because it would not be representative. If the sample is not representative it would be biased and not trustworthy. The term "bias" is not used in this study to indicate a sample that is not representative of universe of inquiry, but it is reserved for the more specific use of referring to the non-compensating errors of the individual observations themselves.

Although random selection is the foundation of all sampling theory, certain departures or improvements can be effected that will insure a sample not only more representative, but more stable than one selected purely on the basis of randomness. The limitations of random selection are well illustrated in dealing four hands of cards in

auction bridge. Each hand of 13 cards is a random sample made up of 25 per cent of the 52 cards and yet one player may get a hand worth several times as much as the hand of some other player from the standpoint of taking tricks. The composition of this especially good hand is not at all representative of the whole deck of cards. Bowley (*2*) suggests four methods that may be used in selecting a representative sample, beginning of course with random selection. These methods are:

RANDOM SELECTION

Random selection is usually known as "simple sampling." A sample is found in such a way that every one of the individuals in the universe of inquiry has the same chance of being selected in the sample, and that the selection of a particular individual does not influence the chance of selecting some other individual. This corresponds to selection on the basis of a lottery. There are various approaches to random selection that do not completely fulfill the requirements, such as every tenth farm along a road. Returns must be made compulsory, otherwise the sample is from only those who are willing to reply. With individual-farm returns from crop reporters the sample is selective of the better type of farmers.

STRATIFIED RANDOM SELECTION

For stratified random selection the universe is subdivided into districts, geographically as crop-reporting districts (or on the basis of some variable as size of farm, tenancy, nativity of farmers), and a number of observations are taken at random in each district. Bowley's original concept of stratified random selection implied that the same size of sample should be selected from each stratum or district and that all strata or districts should be of equal importance. When a sample is selected in this manner it is designated as a proportionately stratified sample to distinguish it from the samples obtained by the method used in crop-estimating work, in which it is impossible ordinarily to select in exact proportion to the acreage in each district or to have the districts all of equal weight. In obtaining a sample in crop estimating, the State is divided into districts, and the average of each district is weighted by the acreage of that crop in the district—a method which will be termed "weighted stratified selection."

PURPOSIVE SELECTION

The term Purposive Selection denotes the method of selecting a number of groups of units in such a way that the selected groups together yield as nearly as possible the same averages or proportions as the totality with respect to those characteristics which are already a matter of statistical knowledge (*3*).

When a sample is secured by the "purposive method," groups of observations are deliberately selected by the statistician, the principle of randomness being entirely disregarded. The judgment of the statistician is substituted for impartial chance, or the mechanical principle, in the selection of the sample. The objective is to select a sample that will have the same characteristics as the whole universe of inquiry.

In selecting these areas or groups of units for the sample the statistician uses, as far as possible, criteria or controls which relate to the field of inquiry. Controls are factors which are known for both the sample and the universe of inquiry, and are correlated with the

unknown quantities that are being investigated. Such areas are selected as will, in their aggregate, give the same results in respect to these control factors as does the universe.

STRATIFIED PURPOSIVE SELECTION

Purposive selection can be made on the basis of a stratified sample. Take for example the partial or sample census of agriculture, which has been proposed as a means of obtaining a reliable indication of change in acreage of the various crops from one year to the next. The selectivity of a voluntary sample, which covers only the farms operated by farmers who are willing to report, would be entirely overcome by a compulsory and complete enumeration, year by year, of all the farms within a number of specified enumeration districts distributed over the State. With the selectivity of the best farmers eliminated, the remaining problem is to select districts geographically representative of the differentiation existing over the entire State or county, constituting the universe of inquiry.

The objective would be to obtain a sample made up of a number of enumeration districts, which would be a replica of the universe of inquiry so far as important factors taken as controls are concerned.

The more nearly the sample is a replica of the universe of inquiry in the year of the census, the more it would tend if enumerated each year, to reflect the changes in acreage of the various crops from year to year. A tabulation by enumeration districts of selected control items from the census schedule would render these items available for both the enumeration districts and the universe as a whole in the year of the census. By a method of sorting and subsorting these enumeration districts, it would be possible to select a sample made up of such districts which would proportionately represent the differentiation of these control items throughout the universe of inquiry, and by the judicious use of "trial and error" in the selection of individual districts, the averages of the sample for these control items could be made to approach very closely to the averages for the universe of inquiry.

In choosing the control items from the census schedule, as a basis for rendering the sample a replica of the universe of inquiry in the year of the census, such factors as might have the highest correlation with changes in acreage and the least intercorrelation between themselves should be selected. This selection would be based on a priori reasoning until sample surveys for two or more years were available for determining just what factors in the farm organization are correlated with changes from year to year in acreages of various crops. The individual farms secured by the sample census for two consecutive years would be used as the units of observation in such a study of relationships. The factors, which might be determined tentatively, should include the acreage in the farm and in each of the various crops, as well as such factors as the number of milk cows and other classes of livestock, proportion of tenants, nativity of farm operators, value of land and buildings, and proportion of produce sold cooperatively.

A simple arithmetical test for representativeness may be applied to any sample when the totals for the entire district or State are known. The percentage relation of the sum of each of the items or control factors in the sample to the total of each for the complete census

enumeration is determined. That is, if the sample contains 5 per cent of the land in farms in the State, does it also contain 5 per cent of the acreage of corn, wheat, oats, hay, and other crops grown as well as 5 per cent of the milk cows, of the number of tenants, of the native-born farm operators, and other factors? The more nearly all the factors approach a given percentage, the more nearly representative is the sample, provided the frequency distribution of these factors within the sample also approaches the distribution within the universe of inquiry.

If this test is satisfactorily met by a sample of individual farms selected at random, it is reasonable to assume that the frequency distribution of the sample corresponds closely to that of the entire universe. When applied to a sample of enumeration districts obtained by purposive selection, it is important that enumeration districts be selected in proportion to the frequency distribution of the universe of inquiry. This simple test is especially helpful in checking up on the representativeness of a sample regardless of the method of selection used.

If the county, rather than the State, is used as the basis for crop and livestock estimates, enumeration districts much smaller than those used by the census would be necessary in order to cover the differentiation that exists within a county. In Alabama, where a sample census has been taken for several years, several routes over each county have been selected, and the farms along these roads are enumerated each year.

This method of purposive selection has been used in several of the Scandinavian countries (*6*, *7*, *8*) for more than 20 years, with excellent results, as a means of estimating crop acreage and production. It is much more reliable than any system based on voluntary crop correspondents and much more timely and inexpensive than a complete enumeration.

With Bowley's classification of methods in mind, the judgment inquiry on crop yields may be designated a "stratified voluntary-judgment sample of crop yields per acre." The sample is not random, nor does it fall under the heading of purposive selection, as returns are only from those who are willing to reply. The statement applies equally well to the individual-farm yield sample. On the other hand, the samples may be considered as highly stratified, and with major crops the returns are closely proportional to the importance of the crop. The breaking up of the State into crop-reporting districts is a form of stratification. The use of the weighted State averages is an excellent and practical substitute for "proportional stratification." Instead of having a random sample within the district, the sample is further stratified because of the fact that the reports received are distributed by townships. The use of county or district weights helps to improve the geographic representativeness by distributing the influence of the sample in proportion to the acreage of the crop. The individual-farm sample by contrast may be designated a "stratified voluntary individual-farm sample of acreage and production," from which crop yields per acre may be derived.

Voluntary reporters may be influenced toward making high estimates of yield per acre by the higher yields obtained on their own farms. This tendency may be further accentuated by the fact that

it is always easier to secure reporters in the better farming localities than in the marginal localities of a county or crop-reporting district.

This limitation of lack of representativeness is serious with all the sampling work of the department. In making estimates this factor is considered and allowed for in so far as it is possible to do so without adequate check information. The use of purposive selection as a method of making a sample census would eliminate this kind of selectivity which is due to the voluntary nature of the reports, as a sample census of representative districts would include all of the farmers in a given district. It then would be a problem of selecting a sample that is geographically representative of the agriculture of a State. A careful and intelligent application of the principles of stratified purposive selection as suggested by Bowley and herein developed, would go a long way towards obtaining a really representative sample of American agriculture that would reflect changes in the acreage of various crops and numbers of livestock on farms from year to year and serve as a partial check on the yield-per-acre samples and furnish other valuable statistical data of high economic value.

ERRORS ENCOUNTERED AND THEIR TREATMENT

From a statistical point of view there is a distinction between mistakes and errors. Mistakes arise from carelessness or incompetency in transcribing and reading figures or from numerical mistakes in computation. The only safe assumption in regard to computation is that mistakes are bound to occur and a system of checking is always necessary. The general policy of the Division of Crop and Livestock Estimates is to have all original computations of sample data verified by a second computer and the corrections verified by the original computer. The calculations that are used on the day of the issuance of the report, in computing production from acreage and yield indications, are always carefully reviewed by one or more members of the Crop Reporting Board. Even with these precautions an occasional mistake is made; it is usually found soon after the release of the report, and the corrected figure is given wide distribution. In a field office there are times when the pressure of work for a crop report becomes so great that it is impossible to verify all computations. A comparison of county averages by the statistician who is thoroughly familiar with the State serves as an effective preliminary check. When the vast number of the calculations made under high pressure is considered it is surprising how few mistakes actually occur.

A comparison of the weighted and unweighted averages serves to show the presence of mistakes in computation. If the two check closely then the probability of a mistake is not high. If they do not check closely either there is a rational explanation of the difference or a mistake has been made. If the number of reports is not in proportion to the weights and there is considerable difference between district averages then a high district average with a large weight will tend to make the weighted average higher than the unweighted average; the opposite situation would result in a weighted average below the unweighted.

PREVENTABLE ERRORS

Errors are encountered in sample data; some types of error may be prevented, but all must be corrected in so far as possible. Misunderstanding of the question, or of the definition attached to the question, is a frequent source of error, especially in the case of questionnaires handled by mail; such mistakes may be serious even when a schedule is filled out by a paid but inadequately instructed enumerator. Carefully preparing the questionnaire and testing the inquiry in a limited way will enable the statistician to avoid many of these sources of misunderstanding. Frequently the condition or the quality of the crop is reported when yield has been requested. If the condition or quality is between 50 and 100 and yields per acre are not running over 25 to 40 bushels, it is comparatively easy to detect these mistakes or errors on the part of the crop reporter and delete the offending figures before the averages are calculated.

The yield of corn is measured and consequently reported in three different units: (1) By the standard bushel, equivalent to 56 pounds of shelled corn, in the Corn Belt States, (2) by the bushel basket of ear corn, actually one-half a standard bushel, in parts of New York, Pennsylvania, and New England, and (3) by the barrel of 5 standard bushels in sections of Maryland. The remedy for such a situation is to ask for the yield per acre of corn in all three units of measure, side by side on the same inquiry. Fundamentally the problem is to know in what terms the farmer usually thinks and then ask the question in those terms. Difficulty arises because the same questionnaire, for reasons of economy, must be used in several States.

When the yield of "all tame hay" is included on the schedule as one question, the average obtained in most States is likely to be lower than when the yield is asked by varieties and the average for each variety is weighted by the acreage of that variety. The farmer does not always include the higher per acre yield of alfalfa in his estimate for all tame hay. His definition of all tame hay is not the same as the one used by the department. During recent years this situation has been corrected by obtaining yields by varieties on a special questionnaire late in the fall after all the hay crops are harvested.

Asking questions concerning facts upon which the informer has no definite information is not only useless work, but it tends to create prejudice against the entire crop-reporting service. It is impossible, for example, to obtain accurate information in most States as to the total quantity of milk produced, or total number of eggs laid, during the previous year or of changes in acreage of the various crops in the locality from year to year. Unless the farmer has sold fluid milk and has a statement of what he sold each month he is likely to be influenced by the more recent production on his farm. It is better to repeat the inquiry periodically and limit the estimate to a day or a week.

It is surprising to observe in how many ways different individuals will reply to a question concerning their estimates of the yield per acre for a hypothetical case that is fully described to them as a group. It is small wonder that printed instructions are sometimes misread, especially if a man is tired from a hard day's work in the harvest field. The statistician must be able to devise a questionnaire that is direct, straightforward, and readily understood, and he must be on the alert to detect reported figures that are apparently the result of misunderstanding the question.

COMPENSATING ERRORS

The worker in the physical laboratory knows that there is no such thing as an absolutely exact measurement. When an object is measured repeatedly and with the greatest care the results are not identical. The most probable value may be obtained by averaging the results of a number of observations provided the errors, or differences, of the separate observations are accidental and tend to balance each other. These compensating errors are spoken of as errors of observation. As Pearson (*13*) says: "In most cases our knowledge does not wait upon certainty, but is described in terms of probability which may approach certainty."

Chaddock (*4, p. 212*) describes the origin of the probable error concept, as follows:

> Gauss made repeated observations of the same phenomenon, as the diameter of a heavenly body in order to increase the accuracy of the observations by averaging. He noted the distribution of these measurements to be in a symmetrical or bell-shaped form about the average or *most probable value.* Their distribution may be characterized as follows:
>
> (1) Small deviations from the mean were more frequent than large.
> (2) Positive and negative deviations were about equally frequent.
> (3) Extremely large deviations did not occur.
>
> He observed this arrangement to be in accord with the usual distribution of chance events and described the resulting frequency curve by a mathematical equation.

The standard error and probable error [6] were developed originally as measures of these accidental and compensating errors of observation. The standard error measures the distance, plus and minus, from the average, within which approximately two-thirds of the observations (measurements) fell; the probable error includes one-half of the observations.

Errors of observation are common in all scientific measurement. They occur in all statistical data whether in a complete enumeration, or a registration, or a sample from a universe of inquiry. Errors of observation are of much greater magnitude in social-science data than in data from the so-called exact sciences. It is difficult for a farmer to estimate accurately the average yield per acre of a given crop in his locality or the number of acres of corn or wheat harvested on his own farm. The grain drill is about the only available measure of acreage for many farmers. Established fields generally are assigned a specified area which is reported from father to son, and never verified. But mere lack of exactness on the part of different observers need not destroy the results of an inquiry, since an estimate made too high by one observer may be compensated for by an estimate made too low by another, and the average from a large number may closely represent the true value.

The errors of observation in either the judgment or the individual farm inquiry on yield per acre are undoubtedly large. Moreover crop correspondents tend to report yields for their locality in rounded numbers [7] that are divisible by 5, such as 5, 10, 15, 25, and 30 bushels.

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[6] The terms, "standard error" and "probable error" are used here with reference to the dispersion of actual observations or the several measurements of a given object or distance, such as the diameter of the moon. This is done in order to explain the origin of the concept that is now used in statistics as a measure of the dispersion of the averages of a number of samples drawn from the same universe, each of which is made up of a number of observations.

[7] See Table 2, Number of reports at specified yields per acre received from township reporters, winter wheat, August, 1928; and Table 3, Number of reports at specified yields per acre received from township reporters, corn, November, 1928.

It is not unusual, with the judgment inquiry to have from 50 to 80 per cent of the reported yields in numbers divisible by 5. Figures divisible by 2 are also popular, but the figure 13 is avoided by most reporters. The reporter is only estimating, and it is reasonable to expect him to make his estimate in rounded numbers. Lack of accurate knowledge concerning yields is also a factor in the situation. *These errors need not affect the accuracy of the average, provided the sample is large enough to enable them fully to compensate.*

NONCOMPENSATING ERRORS, OR "BIAS"

The consideration of noncompensating errors in the sample data, commonly known as "bias," must of necessity be abstract because bias can be measured only when adequate check data for the universe as a whole (from some other source than the sample) are available for direct comparison, and no such information is available with crop yields per acre. The reporters' statements of yields are influenced by the time of year when the inquiry is made, and there are limitations to the use of census enumerations as checks on crop-yield information collected at harvest time. These facts have been discussed.

Bias in its several phases is a form of error found in sample data as well as in complete enumerations and registrations. Biased errors differ from errors of observation in that they are cumulative rather than compensating. They are constant and persistent. A very short person may read the thermometer hanging on the wall and every observation will be above the true reading. No matter how many observations are made by that person the average will never approximate the most probable degree of temperature. It is like using a short yardstick to measure a room. The prejudices, or personal equation, of the informer may influence him to observe only the phenomena that support his views. This personal bias may be intentional or unintentional, but the error becomes cumulative when any appreciable proportion of the observations are so affected.

The form of biased error most difficult to overcome or to make allowance for in making estimates for a universe of inquiry from a sample drawn from that universe is error, intentional or unintentional, resulting from the prejudices or the personal equation of the observer or informer. Such an error is the tendency to exaggerate that which is the center of attention. In years of propaganda of any kind concerning acreage changes or desirable kinds of crops, there is always a distortion of the samples in the direction that the propaganda suggests. Perhaps this is due to the reporters' actually making the suggested changes, while the man who expects to profit by his neighbors' adjustment is not likely to report at all—another example of the possibility of lack of representativeness in the sampling process.

When reporters are asked to give estimates of the acreage of crops harvested on their farms last year, along with the acreage for harvest this year, it is discovered that, when a sufficient number of these reports are compared with what was actually reported currently last year, the acreage of pasture and more important feed crops (such as corn, oats, and hay) check closely, thereby indicating that memory bias was largely compensating and should be classed under errors of observation. But with the minor crops the reporters seem to forget some of the acreage, and the figures taken historically may underestimate the acreage of these minor crops from 5 to 25 per cent, or

possibly more. This is a form of memory bias that must be guarded against. With livestock, the reporter tends to forget the calves and other young stock rather than the adult animals. Although this type of error is unintentional it is cumulative, and no increase in size of sample will overcome it. It is really a form of unintentional psychological bias.

Intentional bias is deliberate understatement or overstatement by the observer. The usual example of this is the marked tendency of women to understate their ages. There is a marked tendency to underestimate the current year's acreage of cash crops, among farmers who report on acreage schedules. The same error exists in the reports on yield per acre or production of important cash crops such as cotton, until the crop has left the owner's hands. Intentional bias undoubtedly is prompted by motives of self interest regarding the effect that supply estimates will have on prices that will be received for the crop, and the tendency is to be over conservative in reporting supply factors to the agency that makes the official Government forecasts and estimates.

There is a pronounced tendency for the yield estimates of cotton to increase as the season advances from October to the following March. (Table 17.) This may be caused by the tendency to report conservatively prior to the final completion of harvest. It is interesting that the reported yields per acre of cotton tend to be higher after nearly all the crop has left the hands of the grower, whereas an opposite tendency is shown with grain crops in most States. In the case of special cash crops intentional bias is always expected, and some allowance is usually made for it.

A distinction should be made and kept in mind between bias due to errors in the data themselves and a discrepancy shown between the average of the sample and that for the universe because of the failure of the sample to be fully representative of the population of the universe of inquiry. The statistician can do a great deal toward improving the representativeness by stratification and weighting, but when the individual observations are subject to biased or cumulative errors, no way of handling the sample will correct for it. The only way to correct fully for bias is to compare the average of the sample with the average for the State as a whole for previous years if check data are available.

It is difficult in a given case to distinguish between lack of representativeness due to the voluntary nature of the sample (that is, the inclusion of the better farmers with the individual farm samples) and bias as herein described. With lack of representativeness the errors are not in the individual observations but appear in the average because the composition of the sample is not the same as the composition of the State as a whole.

There is this similarity, however, in handling the results from a sample that is not representative and a sample that is representative but in which the data are biased. When either type of sample is handled on a relative basis the change shown by the two samples does indicate the change taking place in the universe provided the bias or lack of representativeness is constant with the two samples. This was explained in the discussion of the representativeness of samples.

The importance of developing adequate check-data information on production by obtaining an accurate account of car-lot shipments,

mill-door receipts, etc., can not be overemphasized. Only by developing such check information will it be possible to allow adequately for bias in estimates of production. Unfortunately the bias so measured must be allocated as between acreage samples and yield samples, and there is no very satisfactory way of doing this; nevertheless, such a knowledge is of first importance if the accuracy of official estimates of crop production is to be increased. Already check information of this kind is being used with the cash grains in the spring-wheat States, with fruits and vegetables from commercial areas, and with cotton. With feed crops no such checks are available, and the best possibility for improvement lies in the use of the sample census. The sample census would not eliminate bias from the data, but would make it possible to secure a representative sample.

Through what is called statistician's bias, data may be so edited and handled by an unskilled or prejudiced statistician as to distort the picture. All the very high yields per acre may be eliminated from the sample as being improbable, when such a procedure would not be justified by facts. It is dangerous for the statistician to complete a schedule that has not been entirely filled by the reporter, and this is seldom if ever attempted by an experienced statistician. The State statistician is continually under pressure from the public, especially the agricultural public, and undoubtedly there is a tendency to be conservative in estimating the production of a cash crop, as higher estimates of production may cause lower prices and perhaps a storm of protest from the public. It is the function of the Crop Reporting Board to correct for this kind of bias in making estimates, and it is in better position to do this than is the State statistician, because the members are not so closely in touch with local agricultural affairs in a given State.

MEASURES OF PRECISION OF AVERAGES

PROBABLE ERROR OF THE MEAN

Inevitably the reliability of any conclusion is in some way a function of the number of cases on which it is based. Therefore the sample must be large enough to render the average significant within reasonable limits. If the sample is small and if there is a wide range of yields per acre over a given district, there will be a considerable fluctuation in the averages of samples drawn from this district at random and at the same time.

A conventional measure of the reliability of results, which takes into consideration both the variability in the sample and the number of observations is known as the "probable error of the mean." Pearl (*12, p. 213*) says:

> It is a constant so chosen that when its value is added to and subtracted from the result obtained, or the numeric conclusion reached, it is exactly an even chance that the true result or conclusion lies either inside or outside the limits set by the probable error [of the mean] in the plus and minus direction. * * * The significance of any result is to be judged by its relation to its probable error.

The words included in the brackets were added to Pearl's statement and need amplification. The term "probable error" has been used both for the purpose of the statistical description of a frequency distribution of sample observations and for the purpose of indicating the precision of some generalization, such as the average of a sample. When used for describing the dispersion in a sample it is merely 0.6745

times the standard deviation of the frequency distribution formed by the observations of the sample and should, in fact, be called "probable deviation." When used for the purpose of indicating the precision of some generalization, such as an average, it should be designated as the "probable error of the mean," in order to distinguish it from its use as probable deviation. In this bulletin, for convenience, probable error will be used for the "probable error of the mean," and in no case hereafter will it signify probable deviation.

Keynes (*9, p. 74*) defines probable error "as the name given * * * to an expression which arises when we consider the probability that a given quantity is measured by one of a number of different magnitudes." The average yield per acre from the sample is the most probable measure of the yield for the State, assuming that the sample is fully representative of the universe of inquiry and that the individual observations are free from bias. The amount that the difference between the actual average yield for the entire State and the average yield for the sample is as likely as not to exceed (chances of 1 to 1, or 50 out of 100) is the probable error. The smaller the probable error the greater confidence the statistician has in the average of a sample.

The probable-error concept is ordinarily used to compare the average of the sample with the average for the universe from which the sample is drawn.

> * * * The standard error can be assumed to measure only the errors arising from the fluctuations of simple sampling. * * * Fluctuations due to bias, due to the absence of random selection in the sampling process, due to persistent errors of any sort, quite elude this method of determining probable stability. * * * So serious are these limitations to the employment of the usual measures of probable error in connection with economic data that it would seem generally advisable to subordinate such measures to actual statistical tests of stability. By the study of successive samples, and by the testing of the subordinate elements in a given sample when broken up into significant subgroups, much more may be learned as to the reliability of a given measure and as to the possibility of applying it generally than by unquestioning acceptance and uncritical employment of the usual mathematical formulas for probable error (*10, p. 560–561*).

A comparison of the samples of crop yields received from the field aids and township correspondents such as is made in connection with this study, is in fact a study of successive samples which Mills suggests.

When the several assumptions underlying the ordinary usage of probable error are tested in connection with many kinds of yield-per-acre samples, it is obvious that the ordinary interpretation can not be made with all samples, for all crops, in all States. Consequently in this study the probable-error concept will be used for comparing the average of the sample with the more stable average which would have been obtained from an infinitely large sample taken at the same time and under the same conditions. (See Yule (*18, p. 336, par. 2*).) It also measures the range plus or minus the average of the given sample, within which the probability is 50 out of 100 that the average of a similar sample taken at the same time and under the same conditions is likely to fall. It is an inverse measure of the "precision" of the average as it measures the influence of the fluctuations of sampling.

This somewhat restricted interpretation is a most useful expedient, as it furnishes information concerning a fundamental and universal question in sampling, namely, "is the sample of sufficient size to render the average stable and reasonably free from the influence of the fluctuation of sampling?" When the statistician, through check information (such as cotton ginnings) for previous years, has knowl-

edge of the universe from which the sample was drawn, and when he knows that the underlying assumptions will not hold universally for all samples of crop-yield data, he is not justified in making the ordinary interpretation of probable error. With the large amount of bias that is usually present in the observations of the crop correspondents concerning cotton yields per acre, the ordinary interpretation of probable error is totally inadequate in dealing with estimates of the yield of that crop.

The assumptions that underlie the ordinary use of the probable error concept are as follows:

(1) There is a reasonable degree of homogeneity in the population from which the sample is drawn.
(2) The sample is representative.
(3) The observations in the sample are exact measurements of the phenomena, that is, not subject to errors of observation or compensating errors.
(4) The observations are free from bias or noncompensating errors.
(5) The standard deviation of the sample measures the amount of dispersion in the universe from which the sample is drawn.

Since samples of crop yields per acre are samples of natural phenomena, the first assumption, that of homogeneity, may be conceded, except in those cases in which a State is made up of a number of homogeneous districts that show marked interarea differentiations. Homogeneity is often greatly improved by proper stratification of the sample.

The second assumption, that of representativeness, can be accepted with crop-yield samples in most States when one takes into consideration the methods of minute stratification by townships and crop-reporting districts and the weighting of the returns by counties or districts. In fact this departure from random selection tends to improve the representativeness of the sample.

The third assumption, that the observations are free from compensating errors, never has held in any sample ever taken. Accuracy is a matter of refinement of measurement. Fortunately, even wide errors of observation are not serious, provided the sample is sufficiently large to enable the errors to compensate. The influence of these errors is measured at the same time the influence of the fluctuations of sampling is measured, that is, by the probable error, when the standard deviation of the sample is used to measure the dispersion of the universe.

The fourth assumption, that the individual observations are free from bias, can never be made. Freedom from bias must be established as fact. A complete census does not obviate the difficulty of bias.

The fifth assumption, that the standard deviation of the sample is equal to the standard deviation of the universe, except as it may be influenced by the fluctuation of sampling, is seldom valid with samples collected by means of schedules or questionnaires, where the errors of observation are likely to be large and the measurements contain a large subjective element. At best it can be equal only to the standard deviation of an infinitely large sample taken under similar conditions and subject to the same general limitations as the sample, including errors of observation.

Unless the statistician can use one of Bowley's four methods of selecting a sample and can be sure that the observations are the result of unbiased measurement, he is not justified in using the probable-error concept in the ordinary manner. When the probable error of

the mean is used in this more precise manner the statistician using the material is placed on guard against the possibility that the sample may not be fully representative or that the observations may be biased. The statistician can not afford to take anything for granted, and the assumptions involved must be carefully tested in every way possible. Is the universe reasonably homogeneous? Is the sample fully representative? Are the observations free from noncompensating errors? Is the sample large enough to render the average reasonably stable and free from the fluctuations of sampling? The probable error concept answers only the last of these questions.

That samples subject to as much bias as are cotton yields are of considerable use is evidenced by the high degree of accuracy of the cotton estimates of production during the last three years. When check data are available, as with cotton, the bias of the samples for past years can be determined with considerable accuracy. This bias varies as the result of variations of such factors as the percentage of the crop picked or sold by the time the inquiry is made, the price of the crop, etc. Fortunately bias is much more likely to occur in the case of cash crops for which commercial checks can be obtained, than of crops fed on the farm. Only on the basis of some measurement of bias in past years is it possible to use such samples as cotton yields per acre for estimating purposes. Otherwise it would be impossible to bridge the gap between the average of the infinitely large sample which can be inferred from the current sample to the average for the universe from which the sample was drawn.

This restricted interpretation of probable error eliminates all assumptions concerning representativeness of the sample and of bias in the individual observations, and permits the statistician to proceed on the practical assumption that the infinitely large sample would be subject to the same limitations as the one in hand. With crop-yield data it would continue to be a "voluntary stratified sample" and not a random sample.

The selection of a stratified sample results in greater precision of the average than does the selection of the sample at random. The more homogeneous the districts or subdivisions of the universe, the greater is the precision. Bowley (*3, p. 12, 20*) says:

> Thus increased accuracy is always attained by stratification, unless the attribute is evenly distributed throughout the district, and in some cases the improvement is considerable. * * * If the averages of the districts differ considerably from the general average, or if the standard deviations in the districts are considerably smaller than in the population as a whole, the gain in accuracy by stratification may be considerable.

Not only is the State divided into crop-reporting districts that tend to show less dispersion than does the State as a whole, but the data within the districts are obtained from reporters distributed by townships; this constitutes, in effect, further stratification of the sample. The improvement in accuracy of the district average may be considerable if there are actual differences between the counties and townships that comprise the crop-reporting district. In practice, the matter of increased precision in district averages depends on whether the dispersion of the error of observation of the individual reports is less than the dispersion in the district caused by actual differences in crop yields between localities or townships. This could be tested on the assumption that the extent of the correlation between two series of judgment-yield estimates obtained at the same time from two

correspondents each reporting for the same township would tend to measure the amount of differentiation between townships; or the lack of correlation would indicate that the dispersion due to errors of observation is larger than the dispersion caused by the differentiation that might actually exist between townships.

This test is possible because of the two separate lists of crop correspondents; it is a matter of bringing together two reports from the same township. This test would assume that the locality and township are synonymous; this is not necessarily true, for the reporters may live on opposite sides of a township and each be estimating for a locality centered at his farm; neither of these two men would be estimating for the same locality. In the few samples from a highly homogeneous area in the Corn Belt so analyzed, the correlations have been generally low, about plus 0.40 or 0.50, indicating that the errors of observation are large in comparison with the slight differentiation in average yields per acre for townships. In districts that show greater differentiation higher correlations would be expected.

Bowley (*2, p. 337*) has worked out a method which makes it possible to calculate the effect of stratification on the probable error of the average when the data are drawn in proportion to the importance of the strata, "proportional stratification." Since in practice it is impossible to obtain this type of sample, the system of weighting by crop-reporting districts or by counties is used as a substitute for proportional stratification.

Therefore Bowley's formula for proportional stratification is not fully applicable to crop-yield samples. He has also devised a formula (*2, p. 316*) for ascertaining the probable error of a weighted average which allows the dispersion of the weights to increase materially the size of the probable error. This influence of the dispersion of weights is difficult for the writer fully to rationalize in all cases. Neither of these formulæ seems to apply directly to the problem of measuring the probable error of an average secured from crop-yield samples, especially as neither makes allowance for the increased precision due to the distribution of the crop reporters by townships within the districts.

The probable errors calculated in this study from the usual formula will tend, therefore, to exceed the true probable errors that actually exist, provided allowance could be made for the stratification of the observations by townships and the handling of the sample so as to secure a weighted average for the State. They will not always be strictly comparable as between States or even between different years in the same State because the effectiveness of stratification depends in part on the extent to which the individual districts are more homogeneous than the State as a whole. But an analysis of sample data on a district basis will throw light on the influence of stratification on the precision of the average of the sample. Even with these reservations concerning the instrument that is to be used in the analysis of yield-per-acre samples, such an analysis will be valuable in helping to appraise the reliability and adequacy of crop-yield sample data.

INTERPRETATION AND SIGNIFICANCE OF PROBABLE ERROR

The probable error has already been defined and its use limited to the immediate problem of testing the sample to determine whether it is large enough to be useful as a basis for an estimate of crop yields.

This probable error that is calculated tends to be larger than the true probable error. The more homogeneous the crop-reporting districts as compared with the whole State and the greater the difference between communities and localities within the district the greater will be the effect of stratification and the smaller will be the probable error of the weighted average as compared with the probable error of an unweighted average on the assumption of random selection.

To go a step further, an attempt must be made to visualize the significance of the term probable error or standard error when applied to the average of a sample. Let it be assumed that a large number of samples can be collected that are identical in size to the one already available, and taken at the same time and under similar conditions, from the same universe. All of the samples are to be subject to the same general limitations of the sampling (such as bias, representativeness, selectivity, etc.) as the sample in hand. A sample from the township reporters and another from the field aids constitute an approach to this idea of more than one sample, from the same universe, under similar conditions.

If the averages of all these separate samples were calculated and plotted, it would be found that these averages would form a frequency distribution much more normal in form than that formed by the original observations in an ordinary yield-per-acre sample. If the standard deviation of this frequency distribution of all these means is calculated and multiplied by 0.6745, it will be found that it approaches closely in value to the probable error of the original single sample calculated by the formula

$$\text{Probable error} = \frac{0.6745\sigma}{\sqrt{n-1}}$$

The combined average of all the many samples would be equivalent to the average of an infinitely large sample.

Another demonstration of this principle of the influence of fluctuation of sampling as related to the size of the sample is to draw a sample from a universe, compute an average, draw another sample under precisely the same conditions and observe the averages of the two samples combined; add to these a third sample, and so on, until the average approaches, not continuously, but with some fluctuations, closer and closer to some stable figure. This stable average that would be obtained in a very large sample is thought of as the average of an infinitely large sample.

Knowing the variation in the samples obtained and the number of reports, the probable error can be calculated, and from this it can be determined within what limits improvement in the stability of the average may be expected by increasing the size of the sample.

With a probable error of 1 bushel with an average yield for the sample of 40 bushels it can be said that the chances are equal, or 50 out of 100, that the average of an infinitely large sample taken at the same time and under similar conditions would not differ by more than plus or minus the probable error from the average of the sample—in this case 1 bushel—or that it would fall between 39 and 41 bushels. If, instead, a range of plus or minus 2 bushels (twice the probable error) is taken, the chances are 4.64 to 1 or about 18 out of 100. With three times the probable error the chances are 22.24 to 1 or 4.30 out of 100.

With four times the probable error the chances are 142.3 to 1, or 7 out of 1,000. When the standard error of the mean is used instead, a range of plus or minus three times the standard error indicates that the chances are about 370 to 1 or 27 out of 10,000. These probabilities are computed on the basis of the area of the normal frequency distribution. To approximate the reasonable limits of the possible influence of the fluctuations of sampling, either 3.8 times the probable error or 2.6 times the standard error is used. In either case it can be said that the chances are at least 99 out of 100 that the average of the infinitely large sample will not differ by more than 3.8 times the probable error or 2.6 times the standard error plus or minus from the average of the sample.

The mathematical assumptions underlying these statements are clearly and concisely explained by Pearl (*12, p. 214–215*) as follows:

> Now such statements as these derive whatever meaning they may possibly have from the following simple mathematical considerations. Assuming that the errors of random sampling are distributed strictly in accordance with the normal or Gaussian curve, * * * it is a simple matter to determine from any table of the probability integral the precise portion of the area of a normal curve lying outside any original abscissal limits, or, in other words, the probability of the occurrence of a deviation as great as or greater than the assigned deviation. To say that a deviation as great as or greater than three times the probable error is "certainly significant" means, strictly speaking, that the area of the normal curve beyond 3 P. E. on either side of the central ordinate is negligibly small. As a matter of fact this is not true, unless one chooses to regard 4.3 per cent as a negligible fraction of a quantity. There are certainly many common affairs of life in which it would mean disaster to "neglect" a deviation of 4 per cent of the total quantity involved.

Table 1 (*12, p. 218*) gives the value of the probability and odds for different magnitudes relative to the probable error, and is presented here as an essential part of the above explanation of the significance of the probable-error concept.

TABLE 1.—*Value of probability and odds for different magnitudes relative to probable error*

Deviation ÷ probable error	Probable occurrence of a deviation as great as or greater than designated one in 100 trials	Odds against the occurrence of a deviation as great as or greater than the designated one	Deviation ÷ probable error	Probable occurrence of a deviation as great as or greater than designated one in 100 trials	Odds against the occurrence of a deviation as great as or greater than the designated one
1.0	50.00	1.00 to 1	3.3	2.60	37.42 to 1
1.1	45.81	1.18 to 1	3.4	2.18	44.80 to 1
1.2	41.83	1.39 to 1	3.5	1.82	53.82 to 1
1.3	38.06	1.63 to 1	3.6	1.52	64.89 to 1
1.4	34.50	1.90 to 1	3.7	1.26	78.53 to 1
1.5	31.17	2.21 to 1	3.8	1.04	95.38 to 1
1.6	28.05	2.57 to 1	3.9	.853	116.3 to 1
1.7	25.15	2.98 to 1	4.0	.698	142.3 to 1
1.8	22.47	3.45 to 1	4.1	.569	174.9 to 1
1.9	20.00	4.00 to 1	4.2	.461	215.8 to 1
2.0	17.73	4.64 to 1	4.3	.373	267.2 to 1
2.1	15.67	5.38 to 1	4.4	.300	332.4 to 1
2.2	13.78	6.25 to 1	4.5	.240	415.0 to 1
2.3	12.08	7.28 to 1	4.6	.192	520.4 to 1
2.4	10.55	8.48 to 1	4.7	.152	520.4 to 1
2.5	9.18	9.90 to 1	4.8	.121	828.3 to 1
2.6	7.95	11.58 to 1	4.9	.0950	1,052. to 1
2.7	6.86	13.58 to 1	5.0	.0745	1,341. to 1
2.8	5.89	15.96 to 1	6.0	.0052	19,300. to 1
2.9	5.05	18.82 to 1	7.0	.00023	427,000. to 1
3.0	4.30	22.24 to 1	8.0	.00000668	14,700,000. to 1
3.1	3.65	26.37 to 1	9.0	.00000013	730,000,000. to 1
3.2	3.09	31.36 to 1	10.0	.0000000015	65,000,000,000. to 1

If the statistician wishes to set a limit at which he can say that the probabilities of an occurrence of a deviation as great as the one in hand or greater, is 1 in 100, he will find, by reference to Table 1, that about 3.8 times the probable error will establish this limit. If he is working with the standard error, about 2.6 times the standard error will set this same limit.

CALCULATION OF PROBABLE ERROR AND STANDARD ERROR

The standard error and the probable error are both used to measure the precision of an average. The probable error is equal to 0.6745 times the standard error. Most formulæ are developed in terms of the standard error, but the application of the theory of probability is frequently made in terms of probable error, because the probabilities are 1 to 1, instead of approximately 2 to 1 as with the standard error. The standard error is converted into probable error by multiplying the standard error by 0.6745.

The standard error [8] is calculated by dividing the standard deviation of the population of the universe being sampled by the square root of the number of observations in the sample less one, or

$$\text{Standard error} = \frac{\text{Standard deviation}}{\text{Square root of number of observations less one}} = \frac{\sigma}{\sqrt{n-1}}$$

The probable-error formula is:

$$\text{Probable error} = \frac{0.6745\sigma}{\sqrt{n-1}}$$

These formulæ measure the errors that are likely to occur as a result of the fluctuations of sampling with random selection. The upper limit of this type of error in the sample is set approximately by a figure that is three times the standard error or about four times the probable error.

As soon as a sample has 25 or 30 observations the $(n-1)$ becomes, for all practical purposes, the same as n hence the minus one is disregarded as most of the samples analyzed contain more than 25 observations. Since it is impossible to obtain the standard deviation of the universe we must be content with an approximation of it from the sample. The standard deviation which is calculated from the sample with 25 or more observations will tend to approximate the standard deviation of that part of the universe from which the sample was obtained (*5*). The more representative the sample the more closely will the standard deviation calculated from the sample approximate the true standard deviation of the universe of inquiry. This standard deviation also assumes that the observations are true observations,

[8] The full formula also provides for the effect of having in the sample a larger or smaller proportion of the total number of observations in the universe of inquiry, by adding the term $\sqrt{1-K}$ where K is equal to the number of observations in the sample divided by the number of observations in the universe. The complete formula is therefore,

$$\text{S. E.} = \frac{\sigma}{\sqrt{n-1}} \cdot \sqrt{1-K}$$

If the sample included all the observations in the universe this last term would become zero, and consequently the standard error would also be zero. In samples of crop-estimating data either the universe is considered as infinity or the number of observations is so small that K would be very small indeed (*10*).

which is impossible as all known observational measurements are subject to some error of observation; observations of economic and natural phenomena are likely to be subject to large errors of observation. Consequently the standard deviation used in calculating probable or standard error includes (in addition to the dispersion caused by actual differences in the universe of inquiry), dispersion due to errors of observation. As a result the probable-error concept in practical use really covers the matter of precision in the average of the sample whether the instability is caused by large errors of observation or by differences existing in the universe of inquiry. Yule says (*18*, p. 211) "The effect of errors of observation is, consequently, to increase the standard deviation above its true value." The probable-error formula can be used to indicate how large a sample is needed to give a certain degree of precision when the combined dispersion due to differences in the population of the universe and the errors of observation of the sample data is known approximately and expressed as the standard deviation of the sample.

STATISTICAL INDUCTION

The fundamental importance of the distinction between statistical description and statistical induction has been mentioned. The results of statistical description can be applied only to events actually observed in the sample, but the statistician must go further; he must make an estimate for the universe of inquiry. Mills (*11*) says:

> He seeks generalizations which will apply to a wider group, to events not observed, to cases not included in his sample. He seeks, that is, to employ the ordinary methods of induction, basing the logical processes upon materials of a particular kind—statistical data.

The premises are subject to considerable doubt, as the individual observations are frequently only crude approximations. Complete knowledge of all the observations in a sample of any size is impossible. A multiplicity of causes operate to determine the yield per acre of a given crop. Variation in yields per acre over a given locality, township, county, district, or State is usually pronounced, and even with a representative sample free from bias, an element of probability attaches to every estimate. The calculation of the probable error is a method of measuring the approximate degree of probability in a given case.

The conclusions of all inductive reasoning must be expressed in terms of probability. No average based upon sample data, no matter how numerous these data, is likely to be absolutely identical with the average of the universe from which the sample was drawn. If an average of a sample is to fall within certain prescribed limits of the true average of the universe of inquiry with any finite degree of probability, some assumption must be made about the nature of the universe from which the observations were drawn. The step from a particular sample to an estimate must proceed from some premise about the orderliness of nature, in addition to that premise which takes account of the instances studied. That there should be a reasonable degree of probability in favor of the accuracy of the estimate—the inductive conclusion—it is necessary to make an assumption concerning the finite degree of variation in nature. This general premise of the uniformity of nature in some form is essential in all statistical induction.

So far as the yield per acre of any crop is concerned, there is a limitation to the degree of independent variation possible in the universe of inquiry. Only in exceptional cases does the yield of wheat in Kansas exceed 40 bushels per acre, or the yield of corn in Iowa exceed 80 or 90 bushels per acre. Experience in the field of agriculture justifies the statistician in assuming that the yield per acre for a given crop falls within definite assignable limits. It is extremely important that the statistician have an understanding of the fundamental pattern of the phenomena of the yields per acre for a given crop in a particular State if any considerable weight is to be attached to inductions that he may make in the way of estimates. Mills (*10*) says:

> Quantitative inference of this type differs in no wise from the ordinary process of induction, except in that one of the premises is in quantitative form, and that the conclusion * * * extends an average value, which may or may not hold in any given case. Both evidence and conclusion deal with only probable and approximate relationships or average values, and in this respect accord more closely with actual experience than do the premises and conclusions of universal inductions.
>
> The problem at issue in the discussion of the validity of this process relates to the reliability of the results, to the stability, when applied beyond the sample, of the averages, ratios, or equations computed. The whole practical problem of statistics centers about the stability of such results, and the limits to such stability when the results are generalized in this way.

When the average of a sample of yield-per-acre data is used beyond that sample as an estimate for a definite geographical area, some idea of the limits within which the statistical measure is likely to fluctuate is a practical necessity. The problem involves the theory of inverse or empirical probabilities. "The very foundation of statistical induction, in so far as an attempt is made to measure the stability of the conclusions, rests upon the validity of determining probabilities empirically" (*10*).

The validity of computing probabilities from the results of experience is a controversial subject. Formulæ of probable errors have been developed for computing, from the results obtained from a limited sample, the probability of securing similar results in a study of the larger groups from which the sample was drawn. The controversy centers about the question whether empirical evidence alone is sufficient. Keynes (*9, p. 384*) maintains that the application of mathematical methods to the general problem of statistical inference is invalid.

> To apply these methods to material, unanalyzed in respect of the circumstances of its origin, and without reference to our general body of knowledge, merely on the basis of arithmetic and of those of the characteristics of our material with which the methods of descriptive statistics are competent to deal, can only lead to error and delusion.

Most of the activities of life, however, are based on probabilities that are primarily empirical. Decisions concerning business, engineering operations, industry, life and fire insurance, farming operations, etc., rest upon probabilities that are based on experience—empirical. Pearson (*13*) states that this principle of inverse probabilities rests on the foundation of common sense. In the actual application of statistical methods, empirical probabilities play a dominant part, but this application must necessarily be made in the light of sound reason. The statistician can not place all of his trust in mere mathematical computations of the average of the sample and

the probable error of the average. Unfortunately, basic knowledge of the phenomena that are being sampled is often limited. Men who have worked extensively with crop yields and other samples can go practically all the way with Keynes (*9*) when he says:

> The commonly received opinions as to the bearing of the observed frequencies in a random sample on the constitution of the universe out of which the sample is drawn, though generally stated too precisely and without sufficient insistence on the assumptions they involve, our actual evidence not warranting in general more than an approximate result, are not, I think, fundamentally erroneous. The most usual error in modern method consists in treating too lightly what I have termed above the inductive problem, i. e., the problem of passing from the series S_1, S_2, etc., of which we have observed samples, to the series S of which we have not observed samples.

Accepting the average of a sample of any kind as an absolute figure to represent the true average of the universe from which the sample was drawn, undoubtedly is not scientific procedure. Use of its probable error as the sole basis for interpreting the average of a sample is an important forward step in statistical technic, but appraisal of the reliability and adequacy of the sample can not stop at this point. The statistician must assure himself that the sample in hand actually is meeting the assumptions involved in the concept of statistical induction and in the application of the theorem of inverse probabilities.

Although an array or frequency distribution of the sample data will throw much needed light on the validity of the assumption of the uniformity of nature as applied to yield-per-acre phenomena it does not settle the question. In all of the samples analyzed in this study a frequency distribution of the reported yields per acre of a given crop for the crop-reporting districts and for the State was first made. These distributions were reasonably symmetrical with a tendency to skewness toward the upper limits. This skewness is due to the existence of a positive lower limit of yields per acre below which either the crop is not harvested in any manner or is a failure. The upper range of yields have no such definite limit, as the yields per acre vary considerably over a State and in a few localities may be several times larger than the average for the State. The method of grouping the reports by crop-reporting districts tended to isolate these high yields into a few districts, thereby decreasing the range and dispersion in the remaining districts and rendering the district sample somewhat more homogeneous than the sample for the State as a whole.

In the far western group of States, where there is a great variety of natural conditions even within parts of the same county, the samples showed the least tendency toward symmetry and the normal curve. The regrouping and weighting of the yield samples on the basis of irrigated and nonirrigated acreages, initiated generally for the first time during 1929, will undoubtedly do much to render the samples more homogeneous in these States and strengthens the assumption of uniformity in nature. It suggests the desirability of improving the homogeneity of the crop-reporting districts by a somewhat more logical regrouping of the counties.

The assumption that the observations were selected at random must of course be qualified in the field of voluntary crop reporting. The departure from randomness known as stratification, as practiced by the department in selecting the sample data in reality increases the stability of the average of the sample and results in a probable error somewhat smaller than that resulting from random selection.

The possibility of bias or noncompensating errors in the individual observations makes it necessary to limit the application of the theory of probability to a comparison of the average of a given sample with that of an infinitely large sample of observations similar to the data in the sample. This suggests the imperative need of developing statistical information concerning the universe as a basis for checking the sample data in order that a reliable measure of bias may be determined, that can be used to true-up samples collected in the future. With bias definitely measured, it next becomes a problem to determine the factors that cause bias to vary from year to year, as a basis of ascertaining the most probable amount of bias under a given set of circumstances.

The departure from the principle of pure random selections brings to the foreground the important question of the representativeness of the sample—something that is usually taken for granted when random selection is employed. Representativeness should be tested by the statistician in all the ways his ingenuity can devise, even if he is so situated that he can use random selection.

Years of experience in observing the close agreement of the averages of reports on yields per acre for a given State from the two separate lists of crop correspondents have justified a belief in the stability of these yield-per-acre samples in important producing States. The difficulties involved in attempting to make satisfactory estimates of yields per acre on the basis of available sample data in the far Western States and in some of the minor States and with highly localized crops has led to the analytical work upon which this study is based.

RELIABILITY OF THE ESTIMATES FOR SELECTED CROPS

The analysis of the official estimates of crop yields per acre was undertaken for the purpose of appraising the reliability and adequacy of these estimates and the methods employed in making them. Such an appraisal points out the limitations and the strength of these official estimates for separate crops in various parts of the country. The resulting practical method of analysis can be readily adapted to other types of estimates based on sample data, and to the general use of quantitative data as a basis for inductive generalization and inductive reasoning in the field of economics and related sciences.

Many of the improvements that have been suggested in consequence of this analysis have already been incorporated as a part of the methods now in use by the Department of Agriculture.

This part of the study will be confined to estimates of crop yield per acre for recent years. Many are primarily interested in the reliability and adequacy of current estimates, and especially in the reliability of a comparison of the latest estimates with the yield the previous year or with the 5-year or 10-year average. Others are interested in evaluating the yield-per-acre estimates as a continuous historical series. Some research workers are using these estimates for correlation studies with weather factors as a basis of forecasting crop yields and in other connections. An appraisal of the historical series of estimates of crop yields per acre has been included (p. 129). It is necessarily largely qualitative because of the scarcity of material and information. It consists of a brief résumé of the significant developments in sources of data, methods used, and personnel as they

might be expected to affect the representativeness and size of sample and the possibility of bias.

In the more important agricultural States, where agricultural conditions are not extremely varied, the regular judgment sample as obtained from the regular township and field-aid correspondents has always been, and continues to be, the primary basis of the estimates of crop yields per acre. The individual-farm samples are used to supplement the judgment samples and can be evaluated more advantageously in connection with the estimates of acreage and numbers of livestock, which are based almost entirely on individual-farm returns. The judgment type of inquiry is used also in obtaining sample data on crop yields per acre from business men in agricultural communities. These "special inquiries" as they are called, to distinguish them from the regular monthly inquiries, are limited to the more important cash crops, and their use in a particular State is largely optional with the State statistician. Field observation on the part of trained agricultural statisticians, special samples, individual-farm samples, and check data on production have all been used to supplement the judgment sample from regular crop reporters.

The objective of sampling with the judgment inquiry is to secure a sample that can be used in an absolute rather than a relative sense. It is to secure a yield-per-acre figure which, when multiplied by acreage harvested, will give the total production of a crop for a given State. When experience has shown bias to be present, the average of the sample must be corrected for this bias in so far as possible before it can be utilized as an estimate of yield per acre.

PROCEDURE

The presentation followed in the analysis of the estimates of yields per acre for each of the several crops is as follows:

(1) A general appraisal of the geographic representativeness of the sample is made largely on the basis of a comparison of the straight average (arithmetic mean of all the reports for the State) and the weighted average (district or county averages weighted by estimates of current acreage) of both the township and field-aid samples taken at the same time. A table for each crop is given. These tables, presenting this comparison for each crop, show the two types of averages (from the two corps of crop reporters) for each of two years, by States, along with the official estimates of yields, and the estimates of acreage of the crop harvested.

(2) For two crops, wheat and corn, the frequency distribution of the original observations from the township sample are shown for several States. The distribution of the sample and the tendency of the reports to be made in figures divisible by 5 or by 2 are typical of practically all crops, consequently this type of material was not included for the others. These two tables indicate the possibility of large errors of observation, or errors that are largely compensating, and due to the correspondent's making estimates for his locality in figures divisible by 5 or 2.

(3) The matter of bias (noncompensating errors) in the individual observations of the sample is given consideration. Unfortunately an analysis of the sample itself furnishes no reliable measure of the extent of bias. Bias can be measured only when check information of some kind is available for the State. The ginnings of cotton, for example, as determined by actual count by the Census Bureau, furnish a check on the estimates of production of cotton, but no very satisfactory method has been developed for allocating the existing bias between sample data of acreage changes and sample data of yields per acre. An understatement bias is always expected, but not always found, with all sample data concerning important cash crops. If the sample is to be used in an absolute sense, as with the judgment samples of yields, this is a serious difficulty in making accurate estimates, but if the successive samples are to be used on a relative

basis to indicate change as with individual-farm samples of yields or acreage, this difficulty vanishes entirely, provided there is a constant degree of bias and a closely similar degree of selectivity in the successive samples. Any shift in the degree of bias or selectivity invalidates the use of sample data on a relative basis unless adequate allowance can be made for the change in bias or the samples can be stratified and weighted in such a way as to eliminate the shift in selectivity, as is now done with individual-farm samples of acreage. The experience of the Department of Agriculture in discovering the presence of bias with individual crops is briefly stated in connection with each crop. It is also possible to observe to what extent the Crop Reporting Board has made allowance for bias and selectivity by comparing the final estimates with the sample indications in the tables mentioned above as appearing in connection with the first step of this analytical procedure.

(4) Consideration is given to the experience of the department with the so-called preventable errors, which are due to misunderstanding of the questionnaire, wherever this type of error has been found to have any material influence on the reliability of the sample indications. Customary units of measure vary in different sections of the country. Spring-wheat farmers do not always include durum wheat under the caption of "all spring wheat" on a questionnaire.

(5) The fifth step in this procedure deals with the problem of stability of the sample or the precision of the averages of the sample data. From a study of the sample itself it is possible to gain some idea as to the homogeneity of the universe from which it is drawn and to ascertain whether a given sample is of adequate size and the observations sufficiently concentrated about some central value to give significance to the average of the sample.

The matter of stability and precision is approached in two ways: (1), Somewhat empirically by a comparison of the averages of the two separate samples of township and field-aid reports, taken at the same time and under similar conditions, and (2), by the more technical method of probable error analysis. The tables, previously mentioned under the phase of analysis which treats of the representativeness of the sample, make this comparison possible for both the 1927 and 1928 crops. These comparisons are for all States that grow 10,000 or more acres of a given crop and where the two lists have not been combined. For each of the 14 different crops, usually in several different States, yield-per-acre samples have been subjected to statistical analysis and some of the results are shown in one or more tables for each crop. These tables give illustrations of size of sample, measures of dispersion, and probable error, by States; and in some of the more important States by crop-reporting districts.

A satisfactory distribution of crop reporters by agricultural townships is maintained by eliminating those reporters who fail to report with reasonable regularity and by recruiting new crop reporters promptly to take the places of those who are eliminated. In Iowa, a waiting list is maintained for farmers who wish to serve as crop correspondents. It is extremely difficult to maintain a satisfactory distribution of voluntary correspondents in States that have a scattered agricultural population, as in many of the far Western and Mountain States, or where the farmers speak a foreign language or receive little schooling.

Reports concerning a given crop are received from those districts in which that crop is commonly grown, and consequently with such crops the reports tend to be distributed in about the same pattern as the acreage of the crop, and the straight and weighted averages of a given sample do not differ widely. When the returns are not distributed between districts in proportion to the acreage of the crop, the weighting of the district samples by the acreage of the particular crop for the current year tends to improve the geographic representativeness of the sample and makes the weighted average more representative for the entire State than the unweighted or straight average. Weighting within the crop-reporting districts is considered unnecessary except for those crops the acreage of which is highly localized within limited areas, as is likely with fruit and vegetable crops. With the more universally grown crops the differentiation as to acreage and

yields per acre is usually much greater over a territory as extensive as a State than over a territory approximately only one-ninth of the State.

Even with generally distributed crops, however, in important producing States the final estimates of yield per acre are frequently derived from county estimates made at the close of the season on the basis of a vast amount of supplementary information. That is, the State statistician makes an estimate of acreage and yield per acre and production of a crop for each county on the basis of all available information. When the total production of all the counties for the State is divided by the total acreage, a derived estimate of yield per acre is obtained for the State. This method is feasible when an assessor's enumeration of the acreage devoted to each crop is made each year, as in Kansas, Nebraska, Iowa, and Wisconsin, or where an annual sample census of a representative locality in each county is made each year, as in Alabama.

The tables for each crop by States, for 1927 and 1928, showing the averages obtained from the separate samples from township and field-aid correspondents permit a practical and nontechnical approach to the problem of the stability of the sample and the precision of the averages obtained from the samples of yields per acre. If, for a large group of States in two different years, the weighted averages of the two samples are in close agreement, the observer would be satisfied to conclude that such samples are reasonably stable and that these averages would not be materially altered by increasing the size of the State samples, provided the larger samples were taken at the same time and under similar conditions. It is likely that when such samples are analyzed it will be found that the probable errors are not excessive and that the averages have a high degree of precision.

Such conclusions are justified on the assumption that the two samples for each State, one obtained from township correspondents and one from field aids, are two separate samples taken under practically similar conditions as to time, distribution of reporters, and the system of stratification and weighting used. Some differences between the averages of two such samples do exist in particular States and in certain years. The most important single cause of such differences lies in the method of editing the returns after they are received (either in the State office or in Washington). Generally speaking, the editing of the township returns in the Washington office is a more mechanical and probably a more uniform process as between States than is the editing of the field-aid returns in the various State offices, where the State statistician usually has some direct knowledge of the situation existing in his State.

Take, for example, the problem of editing the yields per acre of a crop when a few correspondents report a zero yield. Zeros should be retained or eliminated, depending on whether the abandonment of acreage has been allowed for in the estimates of acreage. If the estimate of acreage includes only land that was actually harvested, then the zeros should be eliminated before the calculation of the averages for the districts or the State average. But if the estimate of yield per acre is to be made prior to the final revision of the acreage estimates, and there has been more abondonment than usual in a particular season, then some of the zeros should undoubtedly be retained in the sample in order that the estimate of yield can be applied to the current estimate of acreage in obtaining an estimate of produc-

tion. In seasons in which abandonment and crop failure are greater than usual, differences in editing are easily possible and differences between the computed averages of the reports from the two lists of correspondents will tend to reflect greater differences than might be expected merely from the fluctuations of sampling.

The statistical description of the individual sample used in this analysis results in a reduction of the mass phenomenon of yields per acre to several highly significant and important measurable characteristics such as the number of observations, the average, the standard deviation, coefficient of variation, probable error, and relative probable error. Other characteristics of the sample, such as the type of distribution of the observations and skewness, are not quantitatively measured, but are evaluated graphically by inspection.

The yield data for a given crop year and State were tallied by districts so arranged as to form frequency distributions for crop-reporting districts and for the State as a whole. From this tally of the frequency distribution it was possible to determine in a general way the homogeneity of the sample, type of distribution, and skewness, both by districts and for the entire State. Typical frequency distributions for selected States are shown in Tables 2 and 3. From the frequency distribution the average of the sample, the standard deviation and the coefficient of variation are computed by methods described in standard text books on statistical methods. The probable error (of the mean) is computed by the usual formula for samples exceeding 30 observations.[9] The relative probable error is secured by expressing the probable error as a percentage of the average yield.

TABLE 2.—*Number of reports, at specified yields per acre, of winter wheat, received from township reporters, August, 1928*

Reported yield (bushels)	Oregon	Kansas	New Mexico	Washington	Colorado	Utah	Pennsylvania	Illinois
2							1	
3			1					
4		1	2				1	
5					3		14	15
6		1	1		1		3	10
7							7	3
8		5	1		3		16	17
9		3						1
10		16	2	1	7		33	37
11		4					2	2
12	1	30	3	2	2		23	27
13		9			1		5	3
14	1	19	1	1			6	8
15	5	58	2	10	5	3	35	27
16		21		2	1	1	11	9
17		17		1			8	4
18	3	36		3		2	21	23
19		2						4
20	11	76	3	13	11	4	37	46
21		4					4	4
22	1	10		1	2		7	9
23		5		1			4	1
24				1	1		5	3
25	6	33	2	14	4	5	19	16
26		3					3	4
27	1	1		1			5	2
28							3	1
29								
30	8	5	2	15	13	9	4	5
31		1				1		2
32	1						2	
33								
34				1				
35	5		1	2	5	1	1	
36								

[9] Probable error = $\frac{0.6745 \text{ times standard deviation}}{\text{Square root of the number of observations}}$

TABLE 2.—*Number of reports, at specified yields per acre, of winter wheat, received from township reporters, August, 1928.*—Continued

Reported yield (bushels)	Oregon	Kansas	New Mexico	Washington	Colorado	Utah	Pennsylvania	Illinois
37								
38								
39								
40	5			6	6	2	1	
41								
42								
43	1							
44								
45	1			1				
46								
47								
48								
49								
50				1				
Total	50	360	21	77	65	28	281	283

TABLE 3.—*Number of reports, at specified yields per acre, of corn, received from township reporters, November, 1928*

Reported yield (bushels)	Indiana	Iowa	Georgia	Oklahoma	Wyoming	Colorado	Utah	New York
2			1					
3			5					
4			2					
5	1		26	1	1	5		1
6			10			2		1
7			16			2	1	
8	1		32	1		2		
9			3		1			
10	8		61	13	2	7		4
11			5			1		
12	2		27	8	1	5		
13			1	1	1			1
14			4			1		
15	12		37	32	3	17		4
16			3	3				
17			3	6				1
18	5		8	13		2		1
19	1							
20	32	2	19	88	9	16	1	10
21				2				
22	3			10	1			
23				4				
24	1			4	1			
25	55	3	8	44	7	4	1	13
26	2	1		1	1	1		1
27	1	1		2				
28	4	6		5				
29		1						
30	91	26	2	35	3	6	1	20
31				1				1
32	4	7		2				
33	1	1						1
34		5		1				1
35	66	59	3	14	4	4	1	19
36	1	12						4
37		4						1
38	14	19						18
39		1						
40	92	97	1	6		9	2	40
41	1	1						
42		18						1
43	1	3						
45		4						1
46	36	93		3		1	1	13
47	1	5						
48	1	4						
49	3	18						
50	21	62	1	2	1	4	3	28
52	1	5					1	1
55	7	15						1
58		3						1
60	2	19				3	1	14
65	1	3						2
Total	185	500	278	302	36	92	13	204

One purpose of computing the probable error is to determine whether the sample is of sufficient size to give a reasonable degree of stability to the average yield as calculated for the State. Unless there is reasonable stability or precision in the average of the sample obtained from crop correspondents, there is no point from which to measure the bias of the observations or the lack of representativeness of the sample.

The sample analyzed is usually either the township sample or the field-aids sample. If the sample is a combination of the returns from both lists of correspondents or from a special list, it is so designated by a footnote to the table in which it occurs. Consequently, in considering the possible influence of the fluctuation of sampling on the estimate of yield per acre for a given crop in a particular State, allowance should be made for the fact that the basic sample data were composed of two samples, the sample analyzed—perhaps the field aids—and another similar one from the township correspondents of about the same size. Doubling the size of the sample will reduce the probable error nearly 30 per cent. In many States the supplementary sample data on which the final estimate of yield is based are several times as numerous as either the township or field-aids data.

The standard deviation and coefficient of variation both serve as means of describing the dispersion found in the sample, which in turn approximates the dispersion in the universe of crop yields from which the sample is drawn, whether it be the State or the crop-reporting district. The dispersion of the districts is of special interest from the standpoint of the possible influence of stratification of the sample into crop-reporting districts. The smaller the dispersion of the sample within districts as compared with the sample on a State basis measured by the standard deviation, the more effective is the influence of stratification in increasing the precision of the weighted State average above that shown for the straight average.

The probable error of the straight average may be considered as a maximum measure of the influence of the fluctuation of sampling in practically all samples of crop yields per acre. The extent to which the true probable error of the weighted average of yield samples is actually smaller than the probable error of the straight average (as calculated in this study) depends upon the dispersion pattern of yields over a given State. If there is fully as much dispersion in the reports from a county or crop-reporting district as from the entire State, no decrease in probable error is to be expected when the sample is stratified by counties or districts and a weighted average is computed by weighting the averages of these strata. The same reasoning would apply when the universe is stratified by townships and one or more reports are secured from each township. That is, if there is as great dispersion in yields in the townships as for the entire State there is no possibility of reducing the probable error by selecting the crop correspondents by townships. The more homogeneous and uniform the universe of inquiry, the smaller is the reduction in probable error effected by stratification.

The influence of the stratification of the sample into crop-reporting districts may be detected in either of two ways, (1) by comparing the average dispersion of the observations in each district with the dispersion of all the observations on a State basis, or (2) by computing the dispersion of the district averages for the State. The larger this dis-

persion of these district averages, the greater the influence of stratification. This is true because the sum of these two measures of dispersion expressed as variance [10] is equal to the dispersion of all the observations for the entire State when the districts all have equal weights and the samples have the same number of observations from each district. When the weights of the strata are not equal, as is the case with crop-reporting districts, the improvement resulting from stratification tends to be offset by any high degree of dispersion in the weights themselves.

The analysis of the estimates of the yields per acre of winter wheat are made in greater detail than for other crops and forms a standard with which other crops may be compared.

WINTER WHEAT

REPRESENTATIVENESS

The acreage of the winter-wheat crop is generally well distributed over a State geographically; consequently with a sample of the yields per acre as large as that obtained in most States, it is not difficult to obtain geographic representation. In only a few States of importance in winter-wheat production east of the Rocky Mountains is there a difference of more than 1 bushel between the straight average (arithmetic mean of all the reports for the State) and the weighted average (district or county averages weighted by estimates of current acreage) of yields per acre of winter wheat computed from the same sample of reports of crop correspondents. (Table 4.) Rather wide differences exist between the straight and weighted averages of the yield samples in the Mountain and Pacific Coast States. It is difficult to obtain a representative sample in these States. The reports are frequently concentrated in the areas of greatest agricultural population, usually in irrigated sections farmed intensively and growing less wheat than the dry-land areas of the State, from which it is difficult to secure crop reporters. Although weighting county or district averages of yield by acreage tends materially to improve the representativeness of the wheat-yield samples in most States, it is necessary further to stratify and weight the sample within each district on the basis of irrigated and nonirrigated land. As the samples of crop yields in these far Western States have been weighted on the basis of irrigated and nonirrigated land in addition to weighting by crop-reporting districts, since 1929 it is expected that the representativeness of the yield-per-acre samples in these States will be improved.

[10] This concept is used by R. A. Fisher in connection with the explanation of total dispersion in the dependent variable due first to covariation in the independent variable, and second to other factors not associated with the independent variable (*5*).

TABLE 4.—*Winter wheat: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
New York	289	21.9	21.8	22.0	21.5	21.0	306	17.6	16.7	17.6	17.7	14.8
New Jersey	60	23.8	23.2	23.8	22.5	23.0	60	------	------	19.5	19.0	20.0
Pennsylvania	1,090	18.5	18.1	17.9	18.2	18.5	1,101	16.0	15.6	15.1	15.2	15.5
Ohio	1,610	18.1	18.6	17.2	17.8	18.0	864	11.9	11.6	11.4	12.0	10.8
Indiana	1,782	16.0	15.5	16.1	15.8	15.5	900	11.1	11.1	10.2	10.3	10.5
Illinois	2,293	13.9	12.3	14.2	13.2	13.5	1,261	15.6	16.3	14.4	14.5	14.0
Michigan	891	20.9	21.3	21.3	22.0	21.5	882	16.8	16.1	16.1	15.9	16.0
Wisconsin	73	22.5	22.2	23.7	24.1	23.5	42	19.2	18.0	18.1	18.0	18.5
Minnesota	155	21.2	21.6	20.8	21.2	21.4	165	17.3	16.7	16.3	16.0	16.0
Iowa	400	20.1	19.0	19.3	19.3	19.0	411	19.5	19.4	19.5	19.7	19.5
Missouri	1,558	10.2	9.5	10.1	9.9	10.0	1,496	13.4	13.0	13.1	12.5	12.7
South Dakota	105	18.1	17.6	18.6	18.2	18.0	105	14.0	12.1	13.2	11.7	12.0
Nebraska	3,457	20.1	19.5	20.3	19.9	20.5	3,492	18.7	18.4	19.3	19.6	19.1
Kansas	9,936	12.1	10.7	11.5	10.6	11.2	10,433	17.4	16.7	17.5	17.3	17.0
Delaware	98	19.3	------	18.4	21.8	19.0	102	------	------	18.0	------	18.0
Maryland	525	------	------	17.2	17.5	17.5	530	------	------	16.1	16.6	16.5
Virginia	687	11.6	12.0	12.0	12.4	12.2	673	14.0	14.1	14.2	14.8	14.5
West Virginia	135	13.7	13.5	13.5	13.1	13.3	122	12.7	12.4	13.6	13.5	13.0
North Carolina	483	10.7	10.6	11.3	10.8	10.7	441	11.5	11.4	12.4	12.2	11.6
South Carolina	80	11.2	11.1	11.0	10.8	11.0	64	12.3	12.3	13.1	12.6	12.5
Georgia	125	9.7	9.7	9.1	8.8	9.2	94	11.4	11.1	11.4	11.3	11.0
Kentucky	296	10.5	10.0	10.3	9.5	9.5	125	10.9	9.9	9.2	9.4	8.0
Tennessee	528	8.1	8.0	6.6	6.4	7.0	422	9.8	9.8	9.2	9.2	8.8
Arkansas	28	10.9	10.7	15.9	11.8	11.5	22	15.1	13.9	12.0	10.0	11.5
Oklahoma	3,708	9.6	9.1	9.3	9.0	9.0	4,413	12.6	13.6	12.6	13.4	13.5
Texas	1,850	10.2	10.0	11.1	9.4	9.7	2,016	11.8	9.8	11.2	10.1	11.0
Montana	648	18.4	18.8	20.1	19.8	22.0	810	14.9	12.8	15.8	16.0	15.0
Idaho	501	25.5	23.4	26.9	24.0	24.5	456	23.0	21.6	24.9	24.5	23.0
Wyoming	54	21.7	16.1	22.9	22.5	17.0	62	17.8	------	22.3	17.9	15.0
Colorado	1,086	20.5	17.5	18.2	14.4	13.0	923	22.1	19.4	21.2	17.0	12.0
New Mexico	25	15.2	13.4	10.1	3.1	6.0	150	15.7	7.2	16.4	9.9	10.0
Arizona	58	20.0	20.0	23.0	22.5	25.0	47	28.7	------	25.8	21.9	27.0
Utah	152	21.3	20.5	24.9	22.5	19.0	162	25.8	24.6	24.9	24.4	23.0
Nevada	4	27.5	27.5	25.4	25.4	24.0	4	25.7	------	26.4	------	26.0
Washington	1,228	26.6	25.4	28.4	27.6	29.5	1,424	24.6	23.3	28.0	26.2	25.0
Oregon	900	24.0	25.9	26.1	28.6	26.0	837	26.2	28.5	25.4	25.0	24.0
California	812	------	------	18.1	16.8	16.8	780	------	------	21.6	21.0	21.0

[1] Crop reporting district or county averages weighted by acreage weights.

ERRORS OF OBSERVATION

Errors of observation, due to an inaccurate knowledge of the production of a given field, are undoubtedly smaller with a crop like wheat that is threshed and sold than with a feed-grain crop like oats, which is often fed to livestock without being threshed. The tendency to estimate yield per acre in rounded figures divisible by 5 also results in errors of observation. In the group of States shown in Table 2, about 68 per cent of the reports were in figures divisible by 5. The figures divisible by 2 were more popular than odd numbers. Errors of observation are not serious with large samples. Since they tend to increase the standard deviation of the sample beyond that of the universe of inquiry, their influence is inseparable from that of the fluctuation of sampling.

BIAS

Since winter wheat is an important cash crop in many areas, some "cash-crop bias" or understatement in the crop reporter's estimate of yield per acre for his locality might be expected. In no winter-wheat State have the shipments and mill-door receipts of wheat been sufficiently complete to form a reliable check on the accuracy of the estimate of wheat production; consequently no measure of bias is available at present. Such a check is needed and will be obtained eventually when time and funds permit. It is difficult to eliminate duplication of shipments and receipts of out-of-State wheat when milling has grown into an industry of considerable importance in a State consequently, obtaining adequate check data involves more than a mere tabulation of car-lot shipments from the railroads.

In past years the estimates of total wheat production in the United States have frequently been smaller than the supply of wheat that can be accounted for on a national basis from reported grindings, exports and imports of wheat, and estimates of wheat used for feed, seed, and wheat wasted. This fact, combined with the tendency for "cash-crop bias" to appear with crops sold from the farm, leads the statistician to be on his guard against such a bias with winter wheat, especially in instances in which winter wheat is relatively important in comparison with other sources of agricultural income.

There is, however, the long-established impression that crop reporters tend to report yields above the true facts, either because of local pride or because they may be unduly influenced by the higher-than-average yields on their own farms or in their immediate neighborhood. The yields on reporters' farms, as shown by the individual-farm survey, are generally considerably higher than the estimates made by these same reporters for their locality.

With such cash crops as cotton, potatoes, tobacco, peanuts, and fruits and vegetables grown on a commercial scale, for which satisfactory check data on production are obtained, there is a definite and pronounced tendency for understatement on the part of the crop reporter, at least until the crop has left the grower's hands. With winter wheat, however, there is a marked tendency for the yields to be reported lower and lower the further the time of reporting is removed from threshing time. There is no conclusive evidence that cash-crop bias is present in winter wheat yield samples. The Crop Reporting Board showed no appreciable leaning toward the higher of the weighted averages from the two samples in either 1927 or 1928, as might be expected if cash-crop bias were considered by them to be an important factor.

In New York State the official estimate of 21 bushels in 1927 was about 0.6 bushel less than the average of the two weighted averages obtained from the field aids and township reporters. In 1928 the official estimate of 14.8 bushels was 2.4 bushels smaller than were the sample indications. The regular inquiry regarding wheat yield is made the first of August each year. This is before harvest is well under way and entirely too early a date to secure reliable estimates of yields of wheat in New York. The official estimates as they appear in Table 4 were made in December on the basis of a later inquiry.

In New Mexico the official estimate in 1927 was 6 bushels, whereas the township sample showed 15.2 bushels for the straight average and 13.4 bushels for the weighted. The field aids indicated 10.1 bushels

straight and 3.1 bushels weighted. The sample from New Mexico is seldom very trustworthy except in an occasional year when yields are fairly uniform over the State. It is necessary to depend almost entirely on the State statistician's appraisal of the situation in his State, based on meager sample data and direct personal observation and information secured by field travel and correspondence. The ordinary methods of sampling break down in a State like New Mexico. Only 25,000 acres of winter wheat were harvested in 1927; this acreage is scattered over one of the largest of the States. A very small population of farmers, including a high proportion of foreigners who do not read or write the English language easily, makes it impossible to secure an adequate and representative sample. Conditions are so varied over the State, because of differences in topography, elevation, rainfall, and irrigation that the fundamental assumption of uniformity in nature is not valid. It is only by careful stratification of the State and direct personal observation and contact of the State statistician that it is possible to make an estimate of yield per acre in most of these far Western States.

The acreages of winter wheat are small in these States as compared with those in the heavy producing States of Texas, Oklahoma, and in the Corn Belt. The combined acreage of winter wheat for the States of New Mexico, Arizona, Utah, Nevada, and Wyoming, where it is most difficult to secure reliable sample data, is usually less than for such relatively unimportant wheat-producing States as North Carolina and Tennessee.

PRECISION OF THE SAMPLE AVERAGES

One rather practical test of the stability of the yield samples and the precision of the averages is obtained by comparing the weighted averages from the two samples—township and field aids—obtained at the same time, under similar conditions and handled in much the same manner. In Table 4 it can be observed how closely these averages actually correspond in the case of the winter-wheat samples. In 1927 Wisconsin, Tennessee, and Arkansas were the only States east of the Rocky Mountains where the weighted averages of the two samples differed by more than 1 bushel. Winter wheat is of minor importance in Wisconsin and of even less importance in Arkansas. In 1928 Illinois, Nebraska, and Arkansas showed a difference of more than 1 bushel. The closer deletion of the very low yields in the township list, due to heavy abandonment, was responsible for most of the difference between the averages from the two samples for Illinois in 1928.

In the far Western States conditions are more diverse, and the size of sample is necessarily small; the difference between the two samples, exclusive of California, averaged about 3 bushels in 1927. In two of these States, Montana and Idaho, the difference did not exceed 1 bushel, and in five more it did not exceed 3 bushels. Only in Wyoming and New Mexico did the difference exceed 5 bushels, and in these two States the actual dispersion in the universe of wheat yields is extremely wide and the samples unusually small. In 1928 the average difference between the two samples ranged from 0.2 bushel in Utah to as much as 3.2 bushels in Montana and 3.5 bushels in Oregon. It is difficult to obtain a satisfactory sample of wheat yields in these far Western States, and consequently the estimates of wheat

yields per acre have less precision than they have elsewhere in the country.

For most practical purposes this comparison of the weighted averages from the two samples for a large group of States is sufficient to justify the assumption that in States east of the Rocky Mountains the samples of winter-wheat yields are generally stable and have a high degree of precision. But in the far Western States, considerable improvement is needed in the sampling methods of the Department of Agriculture if really dependable averages are to be reached from sample data.

Table 5 presents for comparisons (1) the size of winter wheat yield-per-acre sample, (2) the average yield, (3) the dispersion, (4) variation, and (5) the probable error of the average yield obtained for several different States and for crop-reporting districts in some States. The dispersion of a winter-wheat yield-per-acre sample for an entire State, as measured by the standard deviation of the sample, varies from 3 to 4 bushels in some of the Middle Western and Southern States, in certain years, to as much as 7 to 10 bushels in some of the far Western States; but the average yield per acre is usually so much larger in these far Western States that the coefficient of variation is sometimes no higher than in some of the Central States. In Missouri in 1927 the standard deviation was 3.44 bushels and the coefficient of variation about 35 per cent; in Washington in 1927 the standard deviation was 9.03 bushels and the coefficient of variation only 33 per cent, due to the fact that the average yield in Missouri had been 9.94 bushels and in Washington 27.5 bushels. The coefficient of variation is sometimes more satisfactory as a basis for comparing the dispersion in different samples than is the standard deviation, as it takes into consideration both the standard deviation and the average. It also makes possible a comparison of different crops, some of which are measured in bushels and others in tons or pounds.

TABLE 5.—*Winter wheat: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
Kansas:	*Number*	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
1928	360	17.22	4.43	25.7	0.16	0.9
1	18	16.64	4.10	24.6	.65	3.9
2	53	15.61	4.03	25.8	.37	2.4
3	51	19.51	3.75	19.2	.35	1.8
4	16	16.88	6.18	36.6	1.04	6.2
5	48	17.19	3.78	22.0	.37	2.2
6	40	20.56	4.43	21.5	.47	2.3
7	17	16.76	5.35	31.9	.88	5.3
8	54	15.05	3.88	25.8	.36	2.4
9	63	15.04	4.23	28.1	.36	2.4
1929	645	14.70	6.50	44.2	.17	1.2
1	36	4.40	1.90	43.2	.21	4.8
2	100	7.50	4.30	57.0	.29	3.9
3	86	16.40	4.90	29.9	.36	2.2
4	36	7.80	3.80	48.7	.43	5.5
5	82	15.00	3.50	23.3	.26	1.7
6	88	18.60	4.50	24.2	.32	1.7
7	51	17.60	6.10	34.7	.58	3.3
8	90	18.60	4.10	22.0	.29	1.6
9	76	19.60	4.50	23.0	.35	1.8

Reports from township and field-aid lists combined to constitute the sample.

TABLE 5.—*Winter wheat: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*—Continued

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
Illinois:	*Number*	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
1927	414	13.90	5.67	40.8	0.19	1.4
1	30	19.50	5.35	27.4	.66	3.4
3	30	20.80	5.36	25.8	.66	3.2
4	39	11.80	4.63	39.2	.50	4.2
4a	72	11.20	3.77	33.7	.30	2.7
5	45	16.20	4.53	28.0	.46	2.8
6	60	18.20	3.57	19.6	.31	1.7
6a	63	12.70	3.58	28.2	.30	2.4
7	34	8.40	3.32	39.5	.38	4.5
9	41	9.10	3.00	33.0	.32	3.5
Nebraska:						
1928	232	19.17	4.53	23.6	.20	1.0
1	5	22.80	4.05	17.8	1.22	5.4
2	4	10.50	1.50	14.3	.51	4.9
3	24	20.01	4.37	21.8	.60	3.0
4	15	20.01	4.20	21.0	.73	3.6
5	23	17.10	4.05	23.7	.57	3.3
6	54	19.95	3.63	18.2	.33	1.7
7	33	19.47	4.80	24.7	.56	2.9
8	32	16.71	3.30	19.7	.39	2.3
9	42	20.22	3.77	18.6	.39	1.9
Missouri:						
1927	395	9.94	3.44	34.6	.12	1.2
1	51	13.02	3.05	23.4	.29	2.2
2	36	11.11	2.33	21.0	.26	2.3
3	20	11.33	2.69	23.7	.41	3.6
4	52	11.75	3.20	27.2	.30	2.6
5	85	9.41	3.52	37.4	.26	2.8
6	47	9.32	2.74	29.4	.27	2.9
7	36	7.99	3.07	38.4	.35	4.4
8	52	8.77	2.36	26.9	.22	2.5
9	16	6.75	2.44	36.1	.41	6.1
Michigan:						
1927	407	21.50	5.77	26.8	.19	.9
1925	398	16.50	6.28	38.1	.21	1.3
1922	461	14.70	5.27	35.9	.17	1.2
1920	416	14.90	5.55	37.3	.18	1.2
1919	529	20.00	5.59	28.0	.16	.8
Ohio:						
1929	582	20.40	5.75	28.2	.16	.8
1928	286	12.16	4.77	39.2	.19	1.6
Pennsylvania:						
1927 [2]	799	19.14	6.60	34.4	.16	.8
1927	326	18.02	4.91	27.2	.18	1.0
1926	321	19.05	5.81	30.5	.22	1.2
1925	270	19.69	5.88	29.9	.24	1.2
New York: 1928	126	17.62	5.98	33.9	.36	2.0
New Jersey:						
1928 [3]	56	19.86	5.04	25.4	.45	2.3
1928	115	21.95	5.70	26.0	.36	1.6
2	41	18.93	4.54	24.0	.48	2.5
5	48	21.50	4.93	22.9	.48	2.2
8	26	27.61	3.88	14.1	.51	1.8
Maryland:						
1927	314	16.8	4.66	27.7	.18	1.1
1	12	18.8	5.30	28.2	1.03	5.5
2	230	17.0	4.00	23.5	.18	1.1
3	29	14.0	3.60	25.7	.45	3.2
4	43	18.2	3.50	19.2	.36	2.0

TABLE 5.—*Winter wheat: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*—Continued

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
	Number	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
Virginia						
1927	270	11.50	3.90	33.9	0.16	1.4
1926	288	16.00	4.38	27.4	.17	1.1
2	62	17.30	4.17	23.8	.36	2.1
4	25	17.50	3.68	21.0	.50	2.9
5	66	16.40	3.38	20.6	.28	1.7
6	22	17.00	5.90	34.7	.85	5.0
7	56	16.00	3.71	23.2	.33	2.1
8	46	14.10	3.41	24.2	.34	2.4
9	11	11.60	1.87	16.1	.38	3.3
1924	257	12.70	3.94	31.0	.17	1.3
1921	301	9.20	3.18	34.6	.12	1.3
South Carolina:						
1927	80	11.30	4.53	40.1	.34	3.0
1926	81	15.60	4.61	29.6	.35	2.2
1925	61	11.50	3.92	34.1	.34	3.0
1924	84	12.50	4.38	35.0	.32	2.6
Georgia:						
1927	202	8.40	3.80	45.2	.18	2.1
1925	158	10.20	3.44	33.7	.18	1.8
1924	228	10.20	3.79	37.2	.17	1.7
Oklahoma:						
1927	337	9.60	3.32	34.6	.12	1.3
1	17	9.30	5.56	59.8	.91	9.8
2	82	8.70	2.86	32.9	.21	2.4
3	44	10.00	4.08	40.8	.42	4.2
4	61	10.00	2.64	26.4	.23	2.3
5	45	9.40	2.60	27.7	.26	2.8
7	60	10.60	2.88	27.2	.25	2.4
8	28	8.90	3.10	34.8	.40	4.5
1926	261	15.60	4.08	26.2	.17	1.1
1925	197	8.40	3.09	36.8	.15	1.8
1924	288	15.60	4.97	31.9	.20	1.3
Texas:						
1928	150	10.60	4.56	43.0	.25	2.4
1927	119	9.90	4.64	46.9	.29	2.9
1926	92	17.10	4.54	26.6	.32	1.9
1925	99	6.00	4.10	68.3	.28	4.7
Montana:						
1927	55	21.72	6.49	29.9	.59	2.7
1926	111	11.89	7.59	63.8	.49	4.1
1925	79	16.07	8.15	50.7	.62	3.9
Utah:						
1928	27	25.28	7.12	28.2	.92	3.6
1927	43	21.80	6.66	30.6	.68	3.1
1926	46	25.38	7.75	30.5	.77	3.0
Washington: [1]						
1927	205	27.50	9.03	32.8	.43	1.6
5a	48	23.00	7.05	30.7	.69	3.0
6	49	30.00	4.79	16.0	.46	1.5
1926	174	23.30	9.18	39.4	.47	2.0
5a	34	15.70	6.20	39.5	.72	4.6
6	30	25.20	6.39	25.4	.79	3.1
1925	116	26.70	9.36	35.1	.59	2.2
1924	283	16.50	11.37	68.9	.50	3.0
5a	67	6.90	4.95	71.7	.41	5.9
6	49	20.20	6.14	30.4	.59	2.9
California:						
1927 [1]	135	18.11	6.99	38.6	.41	2.3
1926 [1]	123	17.48	7.67	43.9	.47	2.7
1925 [1]	127	18.70	7.73	41.3	.46	2.5
5	34	18.83	6.19	32.9	.72	3.8
5a	29	18.28	1.57	8.6	.20	1.1

[1] Reports from township and field-aid lists combined to constitute the sample.
[2] Reports from a special list of crop correspondents.
[3] Sample taken in August.

The coefficient of variation for winter-wheat yield samples is frequently lower than 30 per cent in important wheat States such as Kansas, Nebraska, Oklahoma, Texas, Michigan, Ohio, Pennsylvania, and Maryland, and even in Montana in 1927. On the other hand, it may reach 40 to 50 per cent in practically these same States in a year when the average yield per acre is low, as in Kansas in 1926, and Illinois, Georgia, and Texas in 1927. Some of the highest coefficients of variation were 68 per cent in Texas in 1925, when the average yield was 6 bushels per acre; 64 per cent in Montana in 1926; and 69 per cent in Washington in 1924. Practically one-half of the samples of wheat yield per acre, analyzed on a State basis, showed a coefficient of variation between 30 and 40 per cent, and more than a quarter of them were samples with less than 30 per cent dispersion.

The standard deviation in the same State from year to year seems to be more constant than the coefficient of variation because the latter is affected by the variation in the average yield of the sample from year to year. The greatest dispersion in the samples of winter-wheat yields per acre is found in the large Western States, such as Texas, Montana, and Washington, where conditions are extremely varied.

The probable error of the average from the samples is less than 0.2 bushel in most important winter wheat States east of the Rocky Mountains. It is as high as 0.35 bushel in South Carolina, where the sample is small. In the far Western States the probable error is seldom less than 0.4 bushel and in a few cases exceeded 0.8 bushel in the States where the sample was analyzed. In such States as New Mexico and Arizona the dispersion is so large and the sample so small that computation of the probable error is not worth while.

The majority of the winter-wheat samples from the important winter-wheat States east of the Rocky Mountains have a relative probable error of from 1 to 1.5 per cent. The samples from far Western States generally have a relative probable error as low as about 2 per cent in some years, and as high as 4 or 5 per cent in years of low average yields. The small size of sample in South Carolina causes the relative probable error to be as high as 2 or 3 per cent.

The results shown in Table 5 are from the township or field-aid samples, except for Kansas in 1926, Washington, and California, for which the reports from the two lists were combined for analysis. At least two samples similar in size to most of those shown in the table are used as the basis for the Crop Reporting Board's estimate of yields per acre. This doubling of the size of the sample would of course decrease the probable error by nearly 30 per cent from that shown for the single sample for a State. Many of the States have returns on yields from other lists of reporters which supplement the samples received from the regular crop reporters. The individual-farm sample of acreage and production on the reporter's own farm is also used on a relative basis to indicate the change in yields from one year to another in some States.

STRATIFICATION

If the crop-reporting districts in Table 5 show considerably less dispersion than does the State as a whole, there is a reduction in the actual probable error or a gain in the precision of the average. The greater the dispersion in the district averages, the greater the gain in precision. Kansas wheat in 1926 is an example of wide dispersion in yields over a State, as the lowest average yield, 4.4 bushels, with a

standard deviation of 1.9 bushels, was in district 1, and the highest yield, 19.6 bushels, with a standard deviation of 4.5 bushels, was in district 9. When Bowley's formula (*2, p. 337, formula 83*) for the standard error of the mean of a proportionately stratified sample is applied to these data the standard error of the straight average of 0.26 bushel is reduced to 0.16 bushel as the standard error of the stratified sample, a reduction of more than a third. Although the formula does not strictly apply to the weighted stratified sample, it does serve to illustrate the importance of stratification when the individual districts are more homogeneous than is the State as a whole, or when the district averages show marked dispersion.

In the same State in 1928 the effect of stratification was small as compared with that in 1926, for the district averages all fall between 15 and 21 bushels and the standard deviations of the districts averaged about the same as for the State as a whole. It is to be noted, however, in comparing the two years that in 1926 the standard deviation for the State was 6.5 bushels because of the low yields in certain districts, while in 1928 it was only 4.43 bushels. In 1926, when there was wide dispersion in yields of wheat per acre over Kansas, stratification of the sample by crop-reporting districts helped to stabilize the sample and undoubtedly greatly increased the precision of the average.

In Illinois, in 1927, there was a range in district averages from 8.4 to 20.8 bushels. The standard deviation for the State was 5.67 bushels, and yet there were five districts with standard deviations falling below 4 bushels. Stratification by crop-reporting districts reduced the actual probable error materially as the districts were all more homogeneous than the State; that is, they each had a smaller standard deviation.

The two most important winter-wheat districts in the State of Washington show a material difference in their averages, and the standard deviations for the districts were much smaller than for the State as a whole. In 1926 the State standard deviation was 9.18 bushels, whereas in district 5a it was only 6.2 bushels and in district 6 it was 6.39 bushels. In 1927, the standard deviation for the State was 9.03 bushels with 7.05 bushels as the standard deviation of district 5a and only 4.79 bushels in district 6.

In practically every State for which district samples have been analyzed the dispersion in the crop-reporting district tends to be considerably less than for the sample on a State basis.

SIGNIFICANCE OF THE DIFFERENCE BETWEEN TWO AVERAGES

Frequently it is important in the field of economics and statistics to draw conclusions concerning the significance of the difference between two estimates, such as production or yield per acre of a crop in a given State for two successive years. Since conclusions based on sample data must always be in terms of probabilities, it is obvious that the significance of the difference between the averages of two samples must be considered in the same manner.

If the problem of the significance of the averages of samples is approached from the standpoint of the *probable error of the difference between the averages of two samples* for successive years, it is found that in most of the important States a difference of one-half to 1 bushel, or more, may be considered a significant difference. The probable error of the differences with unmatched data (or data from reporters

who do not report for each of the two years) is obtained by adding the square of the two probable errors and extracting the square root. But the two samples contain reports from fully 50 per cent of the same reporters from one year to the next, and there is usually considerable correlation between these paired reports from identical reporters which reduces the probable error of the difference materially. The probable error of the difference in a State like Kansas on the basis of unmatched samples would be about 0.3 bushel. On the basis of reports for the two years that have been brought together or matched, with a correlation of plus 0.60, the probable error of the difference would be less than 0.2 bushel. The correlation of matched data on yields has been, however, as high as plus 0.80 in some instances.

When the proportion of identical reporters is considered, along with other allowances for weighting and stratification of the sample, the statement is well justified that in important States east of the Rocky Mountains a difference between the yield reported one year and the next from the same list of reporters will usually be significant if it exceeds one-half of a bushel. In the far Western States the probable error of the difference might easily reach 1 bushel on the basis of an unmatched sample and probably not less than 0.5 bushel even when allowance for identical farms in the sample is made. In these States the difference between the average yield reported one year and the next from the same list of crop reporters would have to exceed 2 or 3 bushels before it could be assumed that the difference was significant and not due merely to the fluctuation of sampling.

SUMMARY FOR WINTER WHEAT

The probable error of the straight or unweighted average of reported winter-wheat yields in Central and Eastern States on the basis of random selection is around 0.2 of a bushel, or 1 to 1.5 per cent of the average. When allowance is made for the possible effect of the stratification of the sample, it is not likely that the average of a very large sample of wheat yields, taken under similar conditions, would differ from the average of the sample in these States by much more than a half bushel and certainly not by more than a bushel. In the far Western States, where the dispersion in the universe of inquiry is much greater and samples are smaller than in the more populous Central States, the probable error falls between 0.5 to 0.9 bushel, and consequently it is highly probable that the average of a given sample would not differ by more than 1.5 to 3 bushels or 5 to 10 per cent from the average of a very large sample taken under similar conditions.

The conclusions concerning the stability of the sample averages reached from a comparison of the averages from the two lists of crop correspondents shown in Table 4 are practically the same as the conclusions obtained from the more detailed analysis of size of sample, dispersion, and probable error. In the far Western States the yield-per-acre estimates of winter-wheat yields are much less dependable than in the Central and Eastern States, where more uniform conditions prevail and larger and better-distributed samples are obtainable. In these Central and Eastern States "check data" on the commercial movement and utilization of wheat are needed in order that the estimates of the crop reporter may be checked for bias. No increase in the size of sample or change in the method of weighting

to secure a higher degree of representativeness would change the averages of these samples materially, perhaps not more than 1 bushel under ordinary circumstances.

The reliability of the estimates of the yields of winter wheat in the far Western States could be improved somewhat by securing larger and better-distributed samples, by a more careful stratification of the State into districts as homogeneous as possible, and by weighting these more homogeneous districts to obtain more complete representativeness. The sample census would undoubtedly be helpful in the far Western States and would serve as a valuable check on present methods in all other States that grow any appreciable acreage of winter wheat. The method of voluntary sampling breaks down completely in some of these States. In practically all of the Rocky Mountain and Pacific Coast States, extensive field travel, observation, and direct personal contacts with the growers and agencies that handle the crop, are necessary if the State statistician is to make a reasonably satisfactory estimate of yield per acre for winter wheat.

SPRING WHEAT

REPRESENTATIVENESS

Although the acreage of spring wheat is not generally as uniformly distributed over the States in which it is grown as is that of winter wheat, the yield-per-acre sample of spring wheat is apparently nearly as representative geographically as is the yield-per-acre sample of winter wheat. Except in the important spring-wheat States of North Dakota, South Dakota, and Minnesota, there is only a relatively small acreage in the States on the Central West. Even with this small scattered acreage, the differences between straight and weighted averages of the same sample (Table 6) generally fall within a range of 1 bushel or less. In fact, some of the greatest differences occur in the important States of South Dakota and Minnesota. In the far Western States the differences are much greater, as with winter wheat, and in about one-half the cases the difference between the straight and weighted averages exceeds 1 bushel and reaches a maximum of from 4 to 6 bushels in the State of Washington.

TABLE 6.—*Spring wheat: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
New York	12	22.0	21.2	20.3	20.1	18.5	10	16.5	17.0	20.2	21.3	17.3
Illinois	216	16.9	18.3	17.8	18.8	18.0	302	18.1	19.0	17.7	17.6	17.5
Wisconsin	72	20.4	19.7	19.9	19.6	19.8	62	22.2	21.4	21.4	21.1	22.0
Minnesota [2]	1,340	11.9	10.7	11.9	10.8	10.5	1,086	15.7	14.9	15.5	14.6	14.5
Iowa	41	16.5	16.2	15.6	15.7	15.5	41	17.2	17.1	17.6	17.6	17.3
Missouri	10	14.9	13.3	12.7	.....	12.0	15	15.4	15.5	12.0	.....	13.0
North Dakota [2]	6,024	12.0	12.2	12.4	11.8	11.8	5,301	13.4	13.1	13.3	13.4	13.2
South Dakota [2]	1,953	14.4	14.1	15.0	14.9	14.0	1,875	11.2	9.5	11.5	10.6	10.3
Nebraska	173	15.5	16.2	16.4	16.2	17.1	180	16.7	17.3	17.8	19.9	17.9
Kansas	10	11.8	12.5	4.6	5.1	4.4	40	13.7	15.4	11.4	11.9	11.8
Montana [2]	3,187	20.3	19.9	20.7	20.4	20.6	3,410	18.3	18.5	18.2	18.8	19.0
Idaho	670	27.5	27.1	34.8	32.6	30.0	704	27.5	27.9	32.6	30.3	26.0
Wyoming	172	21.9	18.7	23.3	21.9	19.0	181	21.2	18.9	21.1	20.4	17.5
Colorado	333	22.8	21.7	22.0	21.0	18.0	416	22.1	20.6	21.6	21.2	18.0
New Mexico	30	10.9	9.9	21.0	17.1	14.0	36	16.9	15.3	18.0	16.8	15.4
Utah	90	31.6	33.0	32.6	34.2	31.0	95	31.8	33.5	32.5	33.1	32.0
Nevada	14	30.1	27.3	29.3	25.2	26.0	14	26.7	32.1	26.1	26.5	27.0
Washington	1,033	24.7	19.4	25.0	20.5	21.5	847	20.1	13.8	20.8	16.3	15.4
Oregon	165	21.4	23.5	20.7	19.7	20.5	200	20.4	21.3	19.8	16.9	17.0

[1] Crop-reporting district or county averages weighted by acreage.
[2] Exclusive of durum wheat.

BIAS

In the important spring-wheat States of Minnesota, North Dakota, South Dakota, and Montana railroad shipments and mill-door receipts have been used as a check on the production of all wheat. If there were any evidence of cash-crop bias, this check information would have made it possible to detect it as present in either the acreage or the yield-per-acre reports of the correspondents. But since acreage is involved also, no exact measure can be obtained separately for either yield bias or acreage bias. Apparently there was no justification in either 1927 or 1928 for assuming cash-crop bias in the sample, as the final estimates are below the mean of the two weighted averages in Minnesota and North Dakota for both years, and below for one year in South Dakota. It is possible, however, that the estimates of acreage are on too high a level and that consequently the estimates of yield are held low in order that total production may be in line with utilization estimates based primarily on check information. Apparently some bias was allowed for in Montana as the estimates are above either the field-aid or township weighted average in Montana for both years.

PREVENTABLE ERRORS

Only since 1927 have the yields of durum wheat been obtained from the crop reporters separately from "other spring wheat" or "bread wheat" in Minnesota, North Dakota, South Dakota, and Montana. The differences between the straight and weighted averages of the yield samples for durum and bread wheat, taken separately

in 1928, range from 0.2 bushel with both wheats in North Dakota to 0.8 bushel for bread wheat in both Minnesota and South Dakota.

There is a tendency on the part of the crop reporter to consider only bread wheat and not the durum wheat when asked to report on spring-wheat yields. Since durum wheat usually yields more per acre, the estimates of yield per acre for all spring wheat in past years have been lower than they would have been had the yields of the two kinds of wheat been ascertained separately in the three States of Minnesota, North Dakota, and South Dakota. In Montana the acreage of durum is such a small part of the total of all spring wheat that the results could not be appreciably affected.

The two kinds of wheat are now being handled as separate crops, designated as "durum wheat" and "other spring wheat." Anyone combining the two estimates of yield per acre to secure the average yield of all spring wheat in any of these three States should appreciate the lack of comparability between the estimates of the last year or two, and those for previous years. This reporting for bread wheat only is an excellent illustration of what has been designated as a "preventable error"—one that can be avoided by the proper construction of the questionnaire in line with the manner in which the correspondents are most likely to interpret it in answering.

PRECISION OF THE SAMPLE AVERAGES

The spring-wheat yield samples are surprisingly stable when the relatively small acreage in many of the States is taken into consideration. When a comparison is made between the weighted averages of the township and field-aid correspondents, (Table 6) about 80 per cent of the two samples check within a bushel or less in the Central and Eastern States, whereas in the far Western States only about 40 per cent of the samples check as closely as that. The extreme differences are about as large as with sample yields of winter wheat.

Table 7 presents for comparisons (1) the size of spring-wheat yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield obtained for several States. The dispersion of a State spring-wheat yield-per-acre sample, as measured by the standard deviation of the sample, varies from as low as 2.42 bushels in North Dakota in 1920 and 1923, to more than 12 bushels in some of the far Western States such as Idaho and Washington.

The coefficient of variation differs greatly from one year to another, partly because the standard deviation varies and because of differences in the average yield. In North Dakota, the coefficient of variation was 26 per cent in 1920, and 28 per cent in 1927, whereas in 1926 it was 57 per cent. In Montana it was as low as 33 per cent in 1927 and reached 68 per cent in 1925. The greatest variation was found in the State of Washington, when in 1924 it was 77 per cent, a year when the yield per acre was unusually low.

TABLE 7.—*Spring wheat: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
	Number	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
North Dakota:						
1927	405	12.37	3.48	28.1	0.12	1.0
1	74	12.70	3.05	24.0	.24	1.9
2	41	13.30	2.94	22.1	.31	2.3
3	77	10.70	2.73	25.5	.21	2.0
4	37	14.40	2.89	20.0	.32	2.2
5	31	9.50	2.30	24.2	.28	2.9
6	29	10.20	3.01	29.5	.38	3.7
7	35	13.40	3.46	25.8	.39	2.9
8	33	15.00	2.90	19.3	.34	2.3
9	48	10.70	2.69	25.1	.26	2.4
1926	334	8.54	4.86	56.9	.18	2.1
1923	223	7.18	2.42	33.7	.11	1.5
1920	326	9.30	2.42	26.0	.09	1.0
Minnesota:						
1927	404	11.84	3.98	33.6	.13	1.1
1926	446	13.18	4.80	36.4	.15	1.1
1924	437	21.75	5.40	24.8	.17	.8
Montana:						
1927	188	20.74	6.84	33.0	.34	1.6
2	28	24.82	5.74	23.1	.73	2.9
3	37	18.24	6.28	34.4	.70	3.8
5	35	18.86	5.98	31.7	.68	3.6
6	23	18.69	3.96	21.2	.56	3.0
9	20	19.50	5.22	26.8	.79	4.1
1926	223	12.92	7.98	61.8	.36	2.8
1925	237	11.97	8.13	67.9	.36	3.0
Idaho:						
1927	113	34.90	12.70	36.4	.81	2.3
6	32	40.20	9.90	24.6	1.18	2.9
8	31	44.20	7.94	18.0	.96	2.2
1926	80	26.20	10.70	40.8	.81	3.1
1925	131	31.40	10.60	33.8	.62	2.0
1	27	22.00	5.82	26.5	.76	3.5
6	40	35.10	8.97	25.6	.96	2.7
8	33	40.70	10.80	26.5	1.27	3.1
Washington:						
1927	262	24.40	11.33	46.4	.47	1.9
5a	63	18.20	5.07	27.9	.43	2.4
6	42	20.70	6.04	29.2	.63	3.0
1926	250	21.20	11.44	54.0	.49	2.3
5a	55	12.70	4.14	32.6	.38	3.0
6	50	20.90	6.38	30.5	.61	2.9
1925	200	21.90	12.02	54.9	.57	2.6
5a	45	11.90	4.25	35.7	.43	3.6
6	42	19.60	5.92	30.2	.62	3.2
1924	176	15.00	11.50	76.7	.58	3.9

In North Dakota and Minnesota the probable error of the averages of samples is usually less than 0.2 bushel; in Montana it is slightly higher or between 0.3 and 0.4 bushel, and in the State of Washington the probable error was between 0.47 and 0.58 bushel in the four years analyzed. In Idaho, with fully as large a standard deviation and with a smaller sample, the probable error was about 0.8 bushel in both 1926 and 1927.

The relative probable error of the averages of the samples of yield per acre of spring wheat in the important spring-wheat States of North Dakota and Minnesota was between 1 and 2 per cent in the samples analyzed, but in the far Western States it was usually between 2 and 4 per cent.

The spring-wheat yield samples are rather similar to winter-wheat samples from the standpoint of stability and geographic representativeness and bias. In the far Western States the estimates of yield per acre are based on nonrepresentative and inadequate sample data, which must be supplemented by the field statistician. Larger and better-distributed samples, careful stratification of the State, and weighting on the basis of these more homogeneous districts in order to secure a more nearly representative sample would be helpful. The use of check data on the utilization of wheat has brought a high degree of accuracy in the revised estimates of spring-wheat production in the four most important spring-wheat States—Minnesota, North Dakota, South Dakota, and Montana. Dividing the inquiry into questions regarding durum wheat and other spring wheat, and the weighting of the sample by irrigated and dry-land acreage are both forward steps now under way.

RYE

Rye is grown principally in the Northern States, but also as far south as North Carolina, Georgia, Texas, and Oklahoma. More than a third of the rye acreage in the United States is in North Dakota, and Minnesota had about 400,000 acres in 1927 and 1928. Except in these States, rye is of minor importance in the States in which it is produced and is much less generally grown in the far Western States than is either spring or winter wheat. As a result of the small importance of rye and its use for soil-building purposes and for pasture, it is difficult to maintain satisfactory acreage weights that keep up with the changes in acreage. Under these conditions the straight average of yield per acre of rye may be fully as representative as is the weighted average.

REPRESENTATIVENESS

A comparison of the straight and weighted averages from the two samples of township and field-aid reporters for 1927 and 1928 as shown in Table 8 brings out the interesting fact that even with a crop of such minor importance as rye, in 75 per cent of the samples the two types of averages differ by less than 1 bushel. In only a few scattering cases does this difference exceed 2 bushels.

TABLE 8.—*Rye: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average[1]	Average (arithmetic mean)	Weighted average[1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average[1]	Average (arithmetic mean)	Weighted average[1]	Official estimate
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
New York	21	17.8	17.7	17.6	17.7	17.5	20	15.6	15.8	16.1	16.6	15.7
New Jersey	36	18.5	18.9	18.0	21.0	20.0	41	----	----	20.0	19.0	18.5
Pennsylvania	86	16.2	16.3	16.4	16.4	17.0	103	15.3	15.1	15.5	15.6	15.5
Ohio	35	15.7	15.7	15.9	16.3	16.0	30	13.2	13.4	13.4	13.3	13.3
Indiana	119	13.1	13.7	13.6	13.9	13.6	86	11.0	11.1	11.1	11.2	11.0
Illinois	62	13.9	15.4	11.6	14.2	14.5	62	14.8	15.8	14.9	14.6	14.5
Michigan	178	15.3	14.7	15.3	14.7	14.7	182	13.3	13.3	14.0	13.5	13.0
Wisconsin	238	17.5	16.3	17.6	16.8	17.0	167	15.3	13.9	13.8	12.8	13.0
Minnesota	383	18.5	18.4	18.5	18.1	18.3	402	16.0	15.5	14.6	14.6	14.8
Iowa	43	19.3	19.1	17.7	17.6	15.0	49	17.7	17.8	18.3	19.0	18.0
Missouri	16	10.2	10.2	10.6	11.2	11.0	19	12.0	11.4	12.3	12.2	12.0
North Dakota	1,381	16.2	15.8	16.9	17.5	16.7	1,271	10.0	10.2	10.3	10.5	10.0
South Dakota	154	16.7	16.9	19.1	19.0	18.0	162	10.1	8.6	10.4	9.5	9.0
Nebraska	274	16.3	15.5	16.1	14.6	15.0	249	15.7	15.1	15.3	14.6	14.0
Kansas	45	13.0	12.8	14.3	12.7	12.8	32	16.5	16.1	18.0	17.0	16.2
Maryland	14	----	----	15.0	15.3	15.3	15	----	--	14.9	15.0	15.0
Virginia	42	11.3	11.5	11.9	11.8	11.8	46	13.0	13.5	13.0	13.5	13.5
North Carolina	94	13.0	12.6	14.1	13.1	12.0	89	----	----	----	----	11.5
Georgia	26	13.3	11.8	10.2	9.5	10.0	22	----	----	----	----	10.0
Kentucky	14	11.4	11.3	10.6	11.0	11.0	----	----	----	----	----	----
Tennessee	26	8.4	8.3	8.2	8.1	8.0	25	----	----	----	----	8.2
Oklahoma	22	15.7	13.6	15.6	10.9	9.0	26	----	----	----	----	12.0
Texas	14	23.2	21.1	25.0	----	7.0	15	----	----	16.0	----	12.0
Montana	134	15.1	15.4	16.4	16.2	18.0	154	10.5	10.7	15.5	14.1	14.0
Wyoming	54	13.0	10.9	13.7	12.5	12.5	40	15.6	12.4	13.3	12.4	11.0
Colorado	76	12.1	11.7	11.4	9.9	10.5	74	13.8	12.0	12.8	12.2	11.0
Washington	22	15.6	15.3	17.9	18.0	16.0	18	16.3	14.4	20.8	20.6	15.5
Oregon	10	19.7	21.6	17.1	15.4	16.0	----	----	----	----	----	----

[1] Crop reporting district or county averages weighted by acreage weights.

BIAS

In North Dakota, South Dakota, Minnesota, and Montana the railroad shipments and mill-door receipts form the basis for estimates of the utilization of rye that are used as a check on rye production. Only in Montana has it been necessary for the Crop Reporting Board to exceed the averages of the samples in making an estimate of yield per acre. This indicates cash-crop bias in the sample data. This is not clearly defined evidence, however, because errors in acreage as well as yield must be considered when a production check is utilized in this way. No cash-crop bias is expected in States in which rye is a minor crop.

PRECISION OF THE SAMPLE AVERAGES

The rye-yield sample is remarkably stable considering the small acreage in most States, as in only about 35 per cent of the States does the weighted average of the township differ by more than 1 bushel from the weighted average of the field-aid sample. Table 9 presents for comparison (1) the size of rye yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the

average yield obtained for several States. The dispersion of a rye-yield-per-acre sample for a State, as measured by the standard deviation of the sample varies from 4 to 6 bushels in the States where the samples were analyzed, while the coefficient of variation showed a range extending from about 27 per cent to as high as 56 per cent. Only in years of low average yields did the coefficient of variation exceed 45 per cent. This is about the same amount of variation as was shown for samples of wheat yield in these same States.

TABLE 9.—*Rye: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
North Dakota:	*Number*	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
1927	299	15.97	5.28	33.1	0.21	1.3
1	59	15.50	4.85	31.3	.43	2.8
2	33	15.50	3.65	23.5	.43	2.8
3	45	16.20	6.03	37.2	.61	3.8
4	34	16.30	3.87	23.7	.45	2.8
5	38	14.90	3.88	26.0	.42	2.8
6	21	19.60	7.35	37.5	1.08	5.5
7	27	13.90	4.99	35.9	.65	4.7
8	29	15.70	4.28	27.3	.54	3.4
9	13	20.90	6.05	28.9	1.13	5.4
1926	107	7.59	4.29	56.5	.28	3.7
1	13	7.80	4.62	59.2	.86	11.0
2	12	5.00	2.16	43.2	.42	8.4
3	23	8.70	3.60	41.4	.51	5.9
4	10	4.10	1.47	35.9	.31	7.6
5	9	7.00	3.99	57.0	.90	12.9
6	23	12.30	5.25	42.7	.74	6.0
7	5	5.00	2.15	43.0	.65	13.0
9	12	6.40	3.21	50.2	.63	9.8
1923	187	7.29	3.96	54.3	.20	2.7
1920	199	10.49	4.68	44.6	.22	2.1
Minnesota:						
1927	364	18.74	5.31	28.3	.19	1.0
1926	367	13.82	6.14	44.4	.22	1.6
1924	337	19.48	5.37	27.6	.20	1.0
Pennsylvania:						
1927 [1]	399	17.28	4.94	28.6	.17	1.0
1927	176	16.33	4.42	27.1	.22	1.3
1926	176	16.26	4.94	30.4	.25	1.5
1925	177	16.97	4.69	27.6	.24	1.4
Ohio: 1929	174	17.63	5.32	30.2	.27	1.5
Illinois:						
1927	91	11.61	4.97	42.8	.35	3.0
1	13	16.00	3.72	23.3	.70	4.4
3	10	16.60	3.54	21.3	.76	4.6
4	12	10.50	5.73	54.6	1.12	10.7
4a	13	10.00	4.41	44.1	.82	8.2
5	10	10.00	4.02	40.2	.86	8.6
6	7	13.43	3.38	25.2	.86	6.4
6a	14	9.79	2.40	24.5	.43	4.4
7	6	9.00	4.11	45.7	1.13	12.6
9	6	7.00	2.46	35.1	.68	9.7
1927	94	13.80	5.30	38.4	.37	2.7
1926 [2]	158	14.60	5.41	37.1	.29	2.0
1925	147	13.80	5.99	43.4	.33	2.4
1924	109	14.52	6.10	42.0	.39	2.7

[1] Return from a special list of crop correspondents. [2] Reported in August.

The probable error of the averages did not exceed 0.4 bushel in any of the States analyzed, and in 13 of the 17 samples it did not exceed 0.3 bushel. The relative probable error was as low as 1 per cent in three samples and exceeded 3 per cent in North Dakota in 1926 when the average yield was low. Since the estimates of rye yields were based on at least two different samples of this size, the township and the field-aid samples, the combined average from the two samples would have a probable error about 30 per cent smaller than for either taken separately because of the doubling of the size of sample. Although the rye acreage is scattered and the crop is of minor importance in most of the States in which it is grown, the sample indications are nearly as significant as with wheat, and the estimates of yield are nearly as reliable.

CORN

Corn is grown in every State, and in only one State—Nevada—does the acreage fall below 10,000 acres. This makes possible a comparison of samples between a large number of States. There are, however, certain limitations to such comparisons.

Corn is used largely as forage in the northern tier of States. In the Southern States the early planted corn ripens in late summer or early fall, and, in many sections there is a second, late-planted crop, that matures in late fall. When the inquiry regarding corn yield is made on November 1 the southern farmer tends to have the late-planted crop in mind rather than the earlier crop. In 1928 the late crop yielded much better than the early; as a result the estimates of yield per acre covering both crops was reduced below the November 1 sample indications. In many sections of the Northern States corn husking is not sufficiently advanced by November 1 to justify a final estimate of yield at that time. Beginning with 1928 the corn-yield inquiry has been repeated on the December 1 schedule. The estimated yield of corn is not strictly for "grain only" in all States, although the schedule specifies "corn for grain." During the last three years an effort has been made to distinguish between the yield of corn for grain and the yield for other purposes, and as a result, supplementary estimates have been made of the yield for grain, that are separate from the regular grain-equivalent basis.

REPRESENTATIVENESS

The samples of corn yield usually come from points that are distributed over a State in about the same proportion as is the acreage of corn, so a high degree of geographic representativeness is generally attained, except in some of the far Western States, and some of the smaller States where the small number of reports sometimes leads to distortion when district averages are weighted. The straight and weighted averages (Table 10) checked within 1 bushel in over 80 per cent of the samples for the States, exclusive of the far western group where only about 20 per cent of the samples checked as closely as 1 bushel. The acreage of corn is relatively very small in the Western States—7 of the 11 far Western States have less than 100,000 acres of corn each.

TABLE 10.—*Corn: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Maine	14			44.0	46.6	37.0	13			40.1	39.6	40.0
New Hampshire	15			48.0	46.7	41.0	14			44.2	45.3	40.0
Vermont	84			47.0	44.3	39.0	80			46.0	46.7	44.0
Massachusetts	46			49.0	47.4	41.0	45			43.0	45.0	42.0
Rhode Island	10			47.0	47.8	38.0	10			43.3	44 4	39.0
Connecticut	55			48.0	48.1	38.0	55			48.5	45.6	42.0
New York	663	36.8	36.7	38.3	38.2	34.0	650	38.0	37.0	38.0	37.2	34.0
New Jersey	179	43.3	42.4	44.0	40.0	40.0	181			39.0	38.0	38.5
Pennsylvania	1,270	39 1	40.1	39.1	40.0	39.5	1,283	38.8	39.3	39.7	40.5	39.0
Ohio	3,376	36.8	36.6	34 0	34.0	32.5	3,646	37.9	37.8	38.0	38.0	37.5
Indiana	4,205	33.8	33.4	33.6	33.8	31.5	4,440	35.7	36.0	35.4	36.3	35.2
Illinois	8,469	31.4	31.5	31.7	31.7	30.0	9,570	37.3	38.7	38.6	38.8	38.4
Michigan	1,418	28,6	28.8	27.3	27.8	27.5	1,461	33.5	34.3	33.2	33.4	35.0
Wisconsin	2,100	32.8	34.0	33.7	33.4	32.5	2,121	40.6	43.4	44.6	45.2	43.0
Minnesota	4,172	30.8	31.2	30.5	31.3	30.5	4,089	34.5	35.7	34.5	34.7	35.0
Iowa	10,901	35.7	36.4	36.2	36.7	35.5	11,202	43.1	42.9	42.2	42.4	42.6
Missouri	5,796	28.9	28.8	29.5	29.4	29.0	6,260	37.8	30.1	29.1	29.5	29.0
North Dakota	959	26.0	26 0	27.8	27.1	25.0	997	25.8	25.1	25.7	25.6	24.5
South Dakota	4,655	28.3	29.7	29.8	31.6	29.0	4,469	21.8	22.3	22.6	21.8	21.0
Nebraska	8,805	31.8	32.5	31.7	33.1	33.1	8,937	22.8	22.1	21.9	21.4	23.8
Kansas	5,897	31.5	31.8	30.2	29.4	30 0	6,634	27.7	28.2	26.6	26.1	27.0
Delaware	135	34.8		34.0	35.0	35.0	136			29.5	29.9	33.0
Maryland	515			43.3	42.3	44.0	530			37.7	36.3	36.5
Virginia	1,626	30.8	29.9	29.1	29.0	29.5	1,626			27.5	27.6	27.5
West Virginia	441	32.9	32.7	37.4	36.4	33.5	459			38.6	37.9	36.0
North Carolina	2,352	22.9	22.8	23.1	23.2	22.8	2,305	19.7	19.6	19.0	18.8	18.5
South Carolina	1,497	17.4	17.3	16.4	16.8	17.0	1,422	13.1	12.9	12.3	12.1	12.0
Georgia	3,893	15.3	14.5	14.2	13.8	14.0	3,620	11.9	10.8	10.6	10.1	10.5
Florida	573					13.0	607					13.0
Kentucky	2,885	26.4	25.7	28.7	27.2	26.0	3,029	24.5	22.8	26.2	23.6	22.0
Tennessee	2,944	26 7	25.9	24.3	23.7	24.0	2,915	22.8	22.4	19.5	19.7	19.5
Alabama	2,800	16.1	15.7	17.0	16.0	16.0	2,650	14.1	13.5	14.0	14.0	11.5
Mississippi	1,918	18.0	17.9	17.6	17.8	17.8	1,765	14.9	15.0	14.3	14.3	13.0
Arkansas	1,925	21.0	20.7	18.0	18.2	19.0	2,002	18.3	18.4	17.7	17.5	16.5
Louisiana	1,161	18.1	18.7	16.2	16.7	17.5	1,242	16.7	17.6	17.5	17.5	17.0
Oklahoma	3,177	25.0	26.0	25.1	25.1	26.5	3,050	22.5	22.8	21.7	21.9	23.0
Texas	5,189	23.2	22 9	24.0	23.0	23.0	4,722	22.1	21.8	22.8	22.3	21.0
Montana	305	24.1	24.2	23.4	23.6	23.5	274	22.2	20.8	18.3	18.0	19.0
Idaho	76	39.0	39.3	42.3	43.0	41.0	53	44.4	40.9	50.4	49.4	46.0
Wyoming	176	26.2	23.4	23.4	23.4	20.0	167	21.4	20.8	21.4	21.0	18.0
Colorado	1,284	24.6	19.0	22.6	19.5	15.5	1,438	22.2	19.6	22.1	17.4	13.0
New Mexico	166	19.2	17.5	20.5	17.4	15.0	199	24.0	22.4	21.0	23.0	17.5
Arizona	44	40.0	41.8	39.5	43.6	32.0	39	36.7	31.8	42.5	30.9	26.0
Utah	19	35.6	32.9	32.7	31.0	27.0	18	35.5	32.0	30.7	34.3	29.0
Washington	43	41.1	40.4	40.8	34.0	37.0	46	43.8	40.0	44.5	42.0	39.0
Oregon	81	31.8	33.7	34.0	36.0	36.0	82	36.6	37.0	36.3	38.3	36.0
California	77			39.0	33.0	32.0	75			31.2	35.3	32.0

[1] Crop reporting district or county averages weighted by acreage weights.

ERRORS OF OBSERVATION

Table 3 shows the reports from the township reporters for the inquiry of November, 1928, grouped by specified yields per acre of corn. The tendency to report in figures divisible by 5 is pronounced; even in Georgia where the average yield was very low, 57 per cent of the yields were so reported. This tendency is common to all crops, as explained in discussing winter wheat, and is more pronounced in samples of the yield of corn than is the case with wheat. About 68 per cent of the reports in the wheat samples were in such figures,

whereas with corn 78 per cent of the reports in Indiana, 87 per cent in Iowa, and 82 per cent in Colorado were in figures divisible by 5. This practice results in a relatively smaller error of observation on corn than on wheat, because corn yields are generally much higher than wheat yields.

BIAS

Cash-crop bias with corn is ordinarily expected only in States that sell corn, where some bias may be expected, especially in years when the price is very low and there is much discussion in the newspapers about the size of the corn crop and the relation of large and small crops to the price. In Iowa, where the accessors' annual enumeration, taken from January to April, reports the acreage and production of corn for the preceding year, the average yield of corn can be derived and used as a check against the yield samples obtained in November.

In 1925, which was a year of a large corn crop in this country with prices much lower than for the previous year's small crop, the assessors' enumeration showed an average yield of corn of 43.9 bushels which was slightly higher than the weighted average of the township reports of 43.5 bushels and the 43 bushels reported by the field aids. This would seem to indicate the presence of some cash-crop bias in that year. In 1926, although the Iowa crop was nearly 12 per cent less than the year before, the farm price in November of 58 cents per bushel was also lower than the price the year before—61 cents. The assessors found a yield of corn husked or snapped of 39.1 bushels, while the weighted average of the township reports was only 36.3 bushels and that of the field-aid reports was 36.9 bushels, a difference of more than 2 bushels. In both 1927 and 1928 the assessors reported yields of corn lower than the yields reported by the crop reporters. The Iowa farm price in November, 1927, was 69 cents and in November, 1928, was 66 cents. In 1927 the assessors showed 35.2 bushels, as compared with the 36.4 bushels reported by the township list and 36.7 bushels reported by the field-aid list. In 1928 the assessors' report of yield of grain was 41.3 bushels, while the township-list report was 42.9 bushels and the field-aid report was 42.4 bushels.

In 1924, Iowa corn was soft, and only 5 per cent of the crop was reported as having been husked by November 1. Yield of corn for grain in that year as derived from the Federal census enumeration of acreage and production, was 28.3 bushels, whereas the assessors' enumeration for the same year resulted in an average of 28.2 bushels. In the November yield-inquiry 31.6 bushels was reported by the township reporters and 31.2 bushels by the field-aid reporters, whereas on December 1 the field-aid correspondents reported 28.5 bushels.

In Iowa there is apparently a tendency for the crop reporters to overestimate the crop in years of soft corn and to underestimate it in years of well-matured corn. The greater shrinkage in years of soft corn may cause the farmers to report a lower figure late in the winter to the assessor than they estimated on November 1. The present policy of having the yield inquiry repeated in December will undoubtedly greatly improve the estimates of corn yields in the important Corn Belt States.

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PREVENTABLE ERRORS

In parts of New York, Pennsylvania, and New England, the fact that farmers measure the yield of corn in bushel baskets which are equivalent to about one-half a standard bushel has led to the action reported on page 24. It is because of this difficulty that the recent estimates of corn yields in New York and New England are not entirely comparable with estimates of former years. In so far as possible the estimates are now on a standard-bushel basis.

PRECISION OF THE SAMPLE AVERAGES

The samples of corn yield are remarkably stable. Averages of the township and field-aid reports in States east of the Rocky Mountains checked within 1 bushel or less in about 60 per cent of the States in 1927, and in 80 per cent in 1928. The averages from the two samples checked within 2 bushels in the reports from nearly 80 per cent of the States in 1927 and in 97 per cent in 1928. Since corn yields are so much higher than wheat or rye yields, the check of 2 bushels for corn is comparable with 1 bushel for wheat or rye. Even in four of the nine far Western States for which the two samples are available, they checked within a bushel.

In Table 11 are presented for comparisons, (1) the size of corn yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield obtained for several States. The standard deviation of corn yields as reported in samples from individual States varies from as low as 5 or 6 bushels in Mississippi to as high as nearly 12 bushels in certain years in Kentucky and Nebraska In the important Corn Belt States it usually varies between 7 and 11 bushels. In Iowa, where conditions are probably more uniform than in any other State of equal size, the coefficient of variation was as low as 19 or 20 per cent in three out of four years and in the fourth year it was slightly less than 25 per cent. In Illinois and Missouri the coefficient of variation was slightly higher, or about 26 or 27 per cent in the years included in Table 11. In Nebraska it was as low as 24 per cent in 1923 and 27 per cent in 1927, years of high average yields for that State, while in 1926, a year of low yields, the standard deviation was high, and consequently the coefficient of variation reached 67 per cent. The highest coefficient of variation, 73 per cent, was found in the 1926 sample for Montana, when the average yield for the State was only 12 bushels; but in 1927, with an average yield of 22 bushels, it was only 34 per cent. In Texas, the coefficient of variation was as low as 37 per cent in 1926 and as high as 71 per cent in 1925, a year of low yields.

TABLE 11.—*Corn: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
Iowa:	*Number*	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
1928	492	43.15	8.09	18.7	0.25	0.6
1	53	40.85	6.25	15.3	.58	1.4
2	49	41.42	4.27	10.3	.41	1.0
3	61	43.77	8.66	19.8	.75	1.7
4	62	41.05	5.67	13.8	.49	1.2
5	70	45.64	5.96	13.1	.48	1.1
6	50	48.90	7.71	15.8	.74	1.5
7	46	40.65	8.79	21.6	.87	2.1
8	45	42.44	8.28	19.5	.83	2.0
9	56	43.75	7.88	18.0	.71	1.6
1927	901	35.42	8.63	24.4	.19	.5
1	107	36.60	7.10	19.4	.46	1.3
2	97	32.00	6.04	18.9	.41	1.3
3	98	32.50	8.82	27.1	.60	1.8
4	116	39.00	6.94	17.8	.43	1.1
5	115	39.20	6.94	17.7	.44	1.1
6	88	38.50	8.40	21.8	.60	1.6
7	91	38.60	7.78	20.2	.55	1.4
8	104	29.70	8.04	27.1	.53	1.8
9	85	31.40	9.54	30.4	.70	2.2
1926	784	37.40	7.33	19.6	.18	.5
1	93	35.70	7.88	22.1	.55	1.5
2	83	35.96	5.52	15.4	.41	1.1
3	74	37.84	8.06	21.3	.63	1.7
4	95	37.21	7.64	20.5	.53	1.4
5	99	40.86	5.12	12.5	.35	.9
6	92	41.68	7.49	18.0	.53	1.3
7	78	34.10	5.48	16.1	.42	1.2
8	89	33.71	6.56	19.5	.47	1.4
9	81	38.83	7.19	18.5	.54	1.4
1925	885	45.70	9.26	20.3	.21	.5
1	107	36.50	8.74	23.9	.57	1.6
2	100	47.10	7.32	15.5	.49	1.0
3	93	51.80	10.28	19.8	.72	1.4
4	110	44.20	8.74	19.4	.56	1.3
5	112	47.70	6.12	12.8	.39	.8
6	96	52.90	9.04	17.1	.62	1.2
7	85	44.20	5.08	11.5	.37	.8
8	95	42.80	6.52	15.2	.45	1.1
9	87	45.20	8.87	19.6	.64	1.4
Illinois:						
1927	463	31.56	8.14	25.8	.26	.8
1	67	33.81	8.25	24.4	.68	2.0
3	54	30.65	8.11	26.5	.74	2.4
4	52	29.33	8.14	27.8	.76	2.6
4a	68	34.48	11.50	33.4	.94	2.7
5	43	33.50	6.69	20.0	.69	2.1
6	54	32.04	6.61	20.6	.61	1.9
6a	50	27.20	8.38	30.8	.80	2.9
7	45	31.66	7.32	23.1	.74	2.3
9	30	28.50	6.79	23.8	.84	2.9
1926	433	35.27	9.49	26.9	.31	.9
1	46	38.81	8.02	20.7	.80	2.1
3	44	38.75	8.06	20.8	.82	2.1
4	50	38.10	5.91	15.5	.56	1.5
4a	64	33.05	9.50	28.7	.80	2.4
5	43	39.30	7.75	19.7	.80	2.0
6	50	40.20	6.10	15.2	.58	1.4
6a	55	32.55	9.70	29.8	.88	2.7
7	44	27.16	12.40	45.7	1.26	4.6
9	37	30.68	7.07	23.0	.78	2.5

TABLE 11.—*Corn: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*—Continued

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
Michigan:	*Number*	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
1927	492	27.30	11.02	40.4	0.34	1.2
1	6	10.80	12.25	113.4	3.37	31.2
2	46	25.90	11.00	42.5	1.09	4.2
3	9	25.30	12.12	47.9	2.72	10.8
4	27	25.30	10.44	41.3	1.35	5.3
5	43	24.80	11.71	47.2	1.20	4.8
6	51	29.70	10.49	35.3	.99	3.3
7	99	24.10	8.06	33.4	.55	2.3
8	103	28.60	10.06	35.2	.67	2.3
9	108	30.60	12.10	39.5	.79	2.6
Missouri:						
1927	987	29.61	8.12	27.4	.17	.6
1	145	34.62	7.57	21.9	.42	1.2
2	118	30.34	6.88	22.7	.43	1.4
3	77	20.46	8.44	41.3	.65	3.2
4	127	30.67	5.50	17.9	.33	1.1
5	181	29.81	7.95	26.7	.40	1.3
6	116	30.17	8.89	29.5	.56	1.9
7	64	30.15	7.93	26.3	.67	2.2
8	120	29.67	6.96	23.5	.43	1.4
9	39	25.28	7.76	30.7	.84	3.3
Nebraska:						
1928	345	22.01	9.30	42.3	.34	1.5
1927	337	32.05	8.60	26.8	.32	1.0
1926	294	16.95	11.35	67.0	.45	2.7
1925	348	26.35	10.85	41.2	.39	1.5
1924	342	24.25	7.40	30.5	.27	1.1
1923	402	32.16	7.60	23.6	.26	.8
Minnesota:						
1927	508	30.19	11.65	38.6	.35	1.2
1926	481	34.31	10.21	29.8	.31	.9
1924	330	30.56	9.17	30.0	.34	1.1
Virginia:						
1927	327	28.50	9.40	33.0	.35	1.2
2	52	32.60	12.80	39.3	1.20	3.7
4	25	32.20	10.40	32.3	1.40	4.3
5	80	27.60	8.10	29.3	.61	2.2
6	29	28.50	6.20	21.8	.78	2.7
7	64	31.50	9.20	29.2	.78	2.5
8	45	24.30	6.00	24.7	.60	2.5
9	32	26.70	8.60	32.2	1.02	3.8
1926	271	28.50	10.40	36.5	.43	1.5
Kentucky:						
1928	429	24.25	11.46	47.3	.37	1.5
1	56	19.02	8.69	45.7	.78	4.1
2	51	34.90	9.63	27.6	.91	2.6
3	43	24.89	8.79	35.3	.90	3.6
4	60	33.17	6.65	20.0	.58	1.7
5	40	23.50	10.91	46.4	1.16	4.9
6	38	14.08	6.87	48.8	.75	5.3
7	39	17.44	6.88	39.4	.74	4.2
8	64	20.63	8.55	41.4	.72	3.5
9	38	21.19	10.97	51.8	1.20	5.7
1927	428	26.55	9.78	36.8	.32	1.2

TABLE 11.—*Corn: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*—Continued

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
Mississippi:						
1927	*Number* 430	*Bushels* 17.60	*Bushels* 5.51	*Per cent* 31.3	*Bushels* 0.18	*Per cent* 1.0
1	17	22.90	6.75	29.5	1.11	4.8
2	52	16.80	5.30	31.5	.50	3.0
3	59	18.00	5.60	31.1	.49	2.7
4	27	17.80	8.85	49.7	1.15	6.5
5	68	17.10	4.48	26.2	.37	2.2
6	58	16.20	3.81	23.5	.34	2.1
7	38	16.60	4.46	26.9	.49	3.0
8	47	17.60	5.35	30.4	.53	3.0
9	64	18.90	5.10	27.0	.43	2.3
Oklahoma:						
1927	449	24.90	8.20	32.9	.26	1.0
1	14	21.80	4.85	22.2	.87	4.0
2	79	25.60	8.30	32.4	.63	2.5
3	55	25.20	9.10	36.1	.83	3.3
4	56	23.80	11.55	48.5	1.04	4.4
5	80	26.60	7.75	29.1	.58	2.2
6	39	24.50	7.68	31.3	.83	3.4
7	46	24.40	7.60	31.1	.75	3.1
8	52	25.00	7.80	31.2	.73	2.9
9	28	23.80	6.35	26.7	.81	3.4
New Jersey:						
1928	222	40.61	10.85	26.7	.49	1.2
2	61	42.46	11.10	26.1	.96	2.3
5	89	40.50	10.15	25.1	.73	1.8
8	72	39.16	9.55	24.4	.76	1.9
1926	212	45.82	10.75	23.5	.50	1.1
Texas:						
1928	348	20.00	9.17	45.8	.33	1.6
1927	328	22.00	8.73	39.7	.33	1.5
1926	276	26.00	9.50	36.5	.39	1.5
1925	247	11.00	7.80	70.9	.33	3.0
Montana:						
1927	52	22.04	7.48	33.9	.70	3.2
1926	90	12.06	8.78	72.8	.62	5.1

The probable error of the corn-yield averages seldom exceeds 0.5 bushel in a State in which corn is at all important and frequently the probable error is as low as 0.2 or 0.3 bushel in States like Iowa, Illinois, Missouri, and Mississippi. The relative probable error for corn yields is lower than the error for any other crop analyzed; it does not exceed 0.5 or 0.6 per cent in Iowa, and seldom exceeds 1 per cent in Illinois, Missouri, Mississippi, and some of the other States. Only in some of the far Western States such as Montana, or in Texas in years of low yields, does the relative probable error exceed 1.5 per cent. In Iowa the relative probable errors of the crop-reporting district averages fall almost entirely within a range of 1 or 2 per cent; in Illinois, with a much smaller sample, they usually fall between 2 and 3 per cent.

When allowance is made for the effect of stratification and for the fact that at least one additional sample of a size similar to the one analyzed was also included as a basis for the estimate of corn yields, it is evident that in most States the size of sample is sufficient to give an average with a high degree of precision. Geographic representativeness is well taken care of by the distribution of the sample. Cash-crop bias is not likely to be a serious factor except in a few States in which corn is sold, and then only in years of low prices for corn.

Repeating the November 1 yield inquiry in December, making supplementary estimates of "corn for grain only" and allowing for the two crops grown each year in the South are helping to improve the accuracy of the corn estimates. The fact that corn is harvested for other purposes than grain and that different units of measurement are used in different regions, makes estimating the yield difficult. Experimentation in the making of the estimates is undoubtedly improving their basis, and those of the last few years are undoubtedly more reliable than those of previous years.

OATS

Oats, like corn, are widely grown over the entire country. Only four of the smaller States have less than 10,000 acres. Table 12 shows that the straight and weighted averages check closely and that the greatest differences tend to occur in the far Western States with their varied conditions. As with other crops, there is the tendency to report yields in figures divisible by 5, but since oat yields are generally much higher than wheat yields, this tendency is not likely to be a source of error as large as with wheat samples. Since oats are primarily a feed crop, little if any cash-crop bias need be expected. For the same reason a utilization check, based upon car-lot shipments and mill-door receipts, is not conclusive.

TABLE 12.—*Oats: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average[1]	Average (arithmetic mean)	Weighted average[1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average[1]	Average (arithmetic mean)	Weighted average[1]	Official estimate
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Maine	124			35.0	36.5	37.0	120			34.0	35.6	35.0
New Hampshire	11			38.0	39.1	39.0	10			41.0	41.0	39.0
Vermont	83			39.0	38.5	39.0	79			34.0	33.7	34.0
Connecticut	15			34.0	32.6	32.0	15			28.0	25.6	27.0
New York	1,000	35.9	35.9	36.1	35.7	35.0	1,020	27.3	27.6	27.7	28.2	33.0
New Jersey	49	36.0	36.2	39.0	37.0	36.0	50			31.0	30.0	30.0
Pennsylvania	1,100	34.1	34.0	35.7	35.7	36.0	1,067	32.5	32.5	31.8	31.9	32.5
Ohio	1,900	31.3	32.8	31.2	31.6	32.0	2,413	36.0	37.6	35.3	36.6	37.0
Indiana	1,948	23.4	24.2	24.7	24.7	25.0	2,430	36.1	36.7	36.6	37.0	37.0
Illinois	4,008	23.7	24.3	23.7	25.8	25.5	4,649	36.7	37.1	37.6	37.4	37.5
Michigan	1,617	32.0	32.8	33.5	34.4	33.5	1,633	35.3	35.6	35.8	36.1	35.8
Wisconsin	2,422	38.0	38.2	37.9	38.5	38.5	2,495	42.5	42.8	43.7	44.1	43.5
Minnesota	4,350	27.6	28.2	27.5	26.8	26.8	4,089	36.7	36.9	37.5	37.6	36.5
Iowa	6,001	31.3	32.2	31.4	32.5	32.0	6,004	38.8	39.6	40.6	41.0	40.0
Missouri	1,565	18.3	16.4	18.0	18.0	17.0	1,706	27.5	27.2	28.8	28.5	28.0
North Dakota	2,125	23.0	21.6	23.9	21.4	21.5	1,934	31.9	31.3	31.3	30.5	31.0
South Dakota	2,550	28.9	29.0	29.6	29.8	29.3	2,193	27.0	26.2	27.6	27.5	27.0
Nebraska	2,441	27.6	27.4	30.1	28.7	28.6	2,392	31.6	31.2	32.6	32.6	33.0
Kansas	1,301	24.6	23.8	23.4	22.7	23.5	1,301	28.1	27.8	30.0	29.9	29.0
Maryland	51			32.9	33.5	33.5	54			31.4	31.5	31.5
Virginia	186	23.7	22.9	24.1	22.7	21.5	182	25.2	25.0	25.4	25.7	25.5
West Virginia	217	25.8	26.0	24.7	24.1	24.2	204	28.5	28.2	29.0	27.8	28.0
North Carolina	273	18.0	17.1	19.7	19.6	21.0	191	20.3	20.4	22.6	22.4	22.0
South Carolina	449	17.9	17.8	16.8	16.4	23.0	337	21.2	21.1	19.7	20.3	23.0
Georgia	442	15.6	16.4	14.6	14.7	21.0	265	17.4	17.9	18.7		20.0
Florida	11			9.9	10.2	11.0	11			14.6	14.1	17.4
Kentucky	215	19.3	19.7	19.9	19.3	19.0	305	24.3	24.6	28.5	27.6	26.0
Tennessee	179	19.1	18.0	18.5	18.8	17.0	188	22.4	21.7	21.3	21.3	21.5
Alabama	101	16.1	15.9	13.0	14.0	17.5	70	17.7	18.3	17.0	16.0	17.5
Mississippi	18	17.8	16.6	15.7	16.1	19.0	41	19.2	18.6	18.2	18.0	20.0
Arkansas	207	19.6	21.7	18.2	18.6	20.0	155	22.9	24.4	23.4	21.0	22.0
Louisiana	35	17.5	15.0	13.6	12.4	17.5	44	19.1	19.5	23.2	24.3	24.5
Oklahoma	1,112	19.3	19.2	19.4	19.1	19.0	890	26.9	26.9	25.5	25.6	26.0
Texas	2,003	18.6	18.5	21.0	21.5	21.0	1,402	26.9		24.8	25.3	25.5
Montana	596	38.2	37.3	39.9	40.0	40.0	554	35.5	35.3	36.4	35.7	36.5
Idaho	143	44.1	43.1	51.9	48.9	47.0	137	45.2	42.3	53.0	50.0	47.0
Wyoming	120	38.7	36.7	39.3	39.9	56.0	132	35.7	33.0	42.2	35.3	31.0
Colorado	189	36.6	34.3	38.9	36.2	29.0	193	40.5	37.5	37.3	36.2	31.0
New Mexico	30	28.8	26.9	35.1	28.8	22.0	36	22.3	21.6	31.2	32.3	20.0
Arizona	17	40.8	39.5	43.3	41.1	36.0	14	50.0	50.0	42.0	44.0	38.0
Utah	51	49.0	50.8	53.4	54.7	42.0	55	51.7	53.1	50.0	47.0	45.0
Washington	183	52.3	49.0	53.9	49.8	50.0	201	46.9	44.5	51.3	50.6	47.0
Oregon	310	38.9	35.6			34.0	304	38.3	36.3	40.8	36.9	36.0
California	147					28.5	154			36.4	34.4	34.5

[1] Crop reporting district or county averages weighted by acreage weights.

PRECISION OF THE SAMPLE AVERAGES

The samples of oats yields are nearly as stable as the samples of corn yields, with only a few States showing a difference of more than 2 bushels between the weighted averages of the township and field-aid samples. The greatest differences exist in the samples from the South Central and far Western States.

Table 13 presents for comparison: (1) the size of oats yield-per-acre sample, (2) the average yield, (3) standard deviation, (4) variation, and (5) probable error of the average yield obtained for several States. In about one-half the State samples shown in Table 13 the coefficient of variation is less than 30 per cent, but it reached 45 per

cent in Missouri in 1927, when the yield was only about 18 bushels, and it reached 44 per cent in Texas in 1928. In Idaho, the standard deviation was almost double that of the other States, but the high yield of over 50 bushels per acre resulted in a coefficient of variation of less than 28 per cent. The probable error is less than a half bushel in practically all but the far Western States, where the dispersion is always large and the samples are small in size. The probable error was largest in California, in 1927, when there were only 66 reports, and in Idaho, in 1927, when there were only 91 reports. The relative probable error was less than 1 per cent in many of the States but exceeded 2 per cent in South Carolina, Texas, Idaho, and California.

TABLE 13.—*Oats: Yields per acre. Selected illustrations of size of sample measures of dispersion, and probable error*

State, year, and districts	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield or mean	Relative probable error
Iowa:	*Number*	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
1927	995	31.30	9.07	29.0	0.19	0.6
1	119	34.10	6.85	20.1	.42	1.2
2	111	35.00	6.55	18.7	.42	1.2
3	120	29.50	8.30	28.1	.51	1.7
4	108	32.60	6.10	18.7	.40	1.2
5	148	38.40	6.95	18.1	.39	1.0
6	88	32.70	6.90	21.1	.50	1.5
7	89	29.00	6.00	20.7	.43	1.5
8	114	24.00	9.35	39.0	.59	2.5
9	98	22.90	10.35	45.2	.71	3.1
Illinois:						
1928	403	37.80	8.31	22.0	.28	.7
1	54	42.60	8.71	20.4	.80	1.9
3	46	42.30	6.82	16.1	.68	1.6
4	45	40.45	7.88	19.5	.79	2.0
4a	52	39.40	7.33	18.6	.69	1.8
5	50	37.90	7.13	18.8	.63	1.7
6	49	33.15	5.68	17.1	.55	1.7
6a	40	33.00	8.65	26.2	.92	2.8
7	29	34.15	6.58	19.3	.82	2.4
9	29	32.95	7.13	21.6	.89	2.7
North Dakota 1927	393	24.30	9.85	40.5	.34	1.4
1	67	27.60	8.28	30.0	.68	2.5
2	43	25.30	6.42	25.4	.66	2.6
3	75	17.70	6.80	38.4	.53	3.0
4	36	31.70	7.09	22.4	.80	2.5
5	30	19.60	10.08	51.4	1.24	6.3
6	25	16.20	5.49	33.9	.74	4.6
7	34	30.60	8.99	29.4	1.04	3.4
8	40	33.10	7.21	21.8	.77	2.3
9	43	17.60	8.17	46.4	.84	4.8
Ohio: 1928 [1]	440	36.01	9.04	25.1	.29	.8
Michigan: 1927	679	33.70	10.63	31.5	.28	.8
Minnesota: 1927	516	27.74	9.08	32.7	.27	1.0
Missouri: 1927	504	17.69	8.01	45.3	.24	1.4
Nebraska: 1928	295	32.65	8.45	25.9	.33	1.0
New York: 1927	146	35.30	8.60	24.4	.17	.5
Pennsylvania: 1927 [2]	829	36.91	8.36	22.6	.20	.5
South Carolina: 1927	183	21.60	9.20	42.6	.46	2.1
Texas: 1928	174	23.00	10.16	44.2	.52	2.3
Montana: 1927	168	39.80	12.24	30.8	.64	1.6
Washington: 1927	218	52.80	18.51	35.1	.85	1.6
California: 1927	66	31.37	12.20	38.9	1.01	3.2
Idaho:						
1927	91	52.00	14.50	27.9	1.03	2.0
1925	122	50.40	14.00	27.8	.85	1.7
6	38	53.40	13.98	26.2	1.53	2.9
8	30	53.30	12.99	24.4	1.60	3.0

[1] Sample taken in October.
[2] Return from a special list of crop correspondents.

District stratification resulted in districts with smaller standard deviations than the deviations for the State in the three important oat States Iowa, Illinois, and North Dakota. This is to be expected, as oat yields are generally lower the farther south they are grown. The crop-reporting districts would tend to show the higher yields in the more northern districts, and this was the case in Iowa and Illinois.

The averages of the samples of oat yield are so stable that no increase in the size of sample or improvement in method of stratification and weighting would materially change the results in the larger States east of the Rocky Mountains. Even in the far Western States the sample seems to be somewhat more stable than is the case with some of the other crops.

BARLEY

Although barley is now primarily a feed crop it is not as well distributed over the country as corn or oats. Little barley is grown in the southern States. The important spring-wheat States are also the important barley States. The acreage of barley has been increasing rapidly over the Corn Belt during the last four or five years, and it has been difficult to maintain adequate acreage weights for use with yield-per-acre samples. The barley samples for 1927 and 1928, in Table 14, showed a surprisingly close agreement between the straight and weighted averages of the samples. It is not until the far Western States are reached or Texas and Oklahoma are considered, that the straight and weighted averages differ by more than 2 bushels, and even in these States the difference exceeds 2 bushels in only about one-half of the samples. The weighted averages from the township and field-aid samples checked within 1 or 2 bushels in most of the States west of the Rocky Mountains. In these Western States, where great differences exist and where the acreage of the crop and consequently of the samples obtained are very small, the two averages frequently differ by several bushels.

Table 15 presents for comparison (1) the size of barley yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield obtained for several States. The coefficient of variation ranged from a low of 22 per cent in Minnesota in 1924 to 51 per cent in Nebraska in 1926, exceeding 40 per cent in only a few cases, usually in years of low average yields. The standard deviation for barley yields seldom exceeds 8 or 10 bushels. The probable error was less than 0.3 bushel in Iowa, North Dakota, and Minnesota, and exceeded 1 bushel only in States like Pennsylvania that have a small acreage. The relative probable error was as low as 1 per cent in Iowa and Minnesota. For 1925 and 1926 it exceeded 2 per cent in Nebraska, in Pennsylvania, where the sample was very small, and in California, where the dispersion was large.

TABLE 14.—*Barley: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average[1]	Average (arithmetic mean)	Weighted average[1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average[1]	Average (arithmetic mean)	Weighted average[1]	Official estimate
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
New York	188	29.5	30.0	30.6	30.7	29.0	169	27.3	27.6	27.7	28.2	27.5
Pennsylvania	21	27.0	27.2	27.0	27.7	28.0	29	29.4	30.8	27.1	27.4	27.0
Ohio	155	26.9	26.7	27.6	27.4	27.0	333	27.7	27.6	26.7	27.6	27.6
Indiana	35	25.4	24.1	23.5	23.5	23.8	94	25.6	25.6	23.9	23.0	24.0
Illinois	453	27.5	30.0	28.3	29.8	29.5	680	27.5	29.3	28.6	29.7	29.5
Michigan	186	27.3	27.2	29.4	29.0	28.5	270	29.5	29.6	30.7	30.7	30.0
Wisconsin	620	34.1	34.3	34.2	34.5	34.5	725	36.2	36.4	37.1	37.5	37.1
Minnesota	1,460	29.1	28.5	30.7	29.5	30.0	2,000	30.2	28.5	31.0	29.7	30.0
Iowa	454	31.6	31.6	31.8	31.9	31.4	802	32.7	33.2	33.2	34.1	33.5
Missouri	7	25.0	25.0	23.0	23.0	23.0	17	19.7	19.1	24.0	22.0	22.0
North Dakota	1,663	26.8	26.0	25.5	24.7	25.5	2,179	26.4	25.8	26.0	25.3	25.5
South Dakota	1,200	30.1	30.0	30.6	30.1	30.1	1,644	24.2	21.5	23.5	21.9	21.7
Nebraska	246	28.7	29.8	30.0	31.2	30.8	430	30.7	30.6	31.3	33.7	32.6
Kansas	452	18.8	17.1	17.6	14.6	12.6	633	25.9	25.7	28.3	28.5	27.9
Maryland	9	------	------	30.7	30.5	30.5	13	------	------	31.4	31.6	31.0
Virginia	13	26.0	26.3	26.0	25.6	26.0	14	30.0	30.2	30.5	30.5	29.0
North Carolina	20	22.0	------	25.1	------	24.0	32	21.8	------	25.4	23.2	23.0
Tennessee	42	18.3	17.6	21.0	------	19.0	21	24.3	23.6	22.0	------	20.0
Oklahoma	36	16.6	13.1	18.9	17.9	16.5	23	23.0	24.9	20.7	22.3	22.0
Texas	195	18.2	14.6	18.0	16.0	16.0	156	21.6	18.4	20.2	20.6	21.0
Montana	195	33.1	32.6	32.7	32.6	33.0	209	29.1	29.2	30.7	30.7	30.5
Idaho	129	40.3	40.7	49.5	45.6	44.0	144	36.4	35.4	49.0	47.0	43.0
Wyoming	59	33.6	34.8	36.9	37.9	34.0	77	33.1	30.4	33.5	34.3	30.0
Colorado	410	30.5	23.8	32.6	26.9	22.0	547	33.1	26.7	30.9	28.7	24.0
New Mexico	8	23.3	22.0	28.5	22.6	18.0	12	26.2	24.9	28.1	32.3	19.0
Arizona	20	33.8	34.0	35.9	36.4	35.0	17	40.0	40.0	38.0	39.0	38.0
Utah	30	46.3	47.5	48.9	52.7	47.0	34	52.4	50.1	52.0	52.9	49.0
Nevada	9	45.5	38.5	53.9	55.2	45.0	11	43.0	46.7	37.0	36.1	40.0
Washington	58	40.1	38.6	43.0	41.8	42.0	55	37.2	35.6	37.3	35.3	35.5
Oregon	91	38.9	38.9	35.5	35.4	35.0	105	34.4	34.5	36.0	------	35.0
California	994	------	------	------	------	27.5	1,044	------	------	31.4	30.4	30.5

[1] Crop reporting district or county averages weighted by acreage weights.

Stratification of the State into crop-reporting districts resulted in district samples with standard deviations materially smaller than those for the State as a whole, in both Iowa and North Dakota.

The samples of barley yields show less stability and the averages have less precision than do those of either oats or corn. This is to be expected as barley is a major crop in only a few States, such as Minnesota, North Dakota, and South Dakota. In some of the States with small acreage and small samples some increase in size of sample would undoubtedly improve the precision of the sample averages, but barley is of such minor importance as a crop in most of these States that it would hardly be worth while, considering the facilities available at present, to enlarge the sample.

TABLE 15.—*Barley: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
Iowa:	*Number*	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
1927	634	31.50	7.67	24.3	0.21	0.7
1	103	34.00	6.70	19.7	.45	1.3
2	94	34.60	6.61	19.1	.46	1.3
3	90	31.20	7.36	23.6	.52	1.7
4	78	31.70	6.90	21.8	.53	1.7
5	97	33.40	7.54	22.6	.52	1.6
6	58	29.00	7.30	25.2	.65	2.2
7	58	25.80	6.00	23.3	.53	2.1
8	41	28.50	8.94	31.4	.94	3.3
9	15	24.70	7.84	31.7	1.37	5.5
1926	478	31.00	8.75	28.2	.27	.9
1925	490	32.80	8.20	25.0	.25	.8
North Dakota:						
1927	401	26.80	8.05	30.0	.27	1.0
1	71	28.60	7.47	26.1	.60	2.1
2	37	27.80	7.59	27.3	.84	3.0
3	84	20.80	5.24	25.2	.39	1.9
4	33	32.20	9.62	29.9	1.13	3.5
5	32	25.50	7.22	28.3	.86	3.4
6	31	25.90	6.47	25.0	.78	3.0
7	31	30.30	8.28	27.3	1.00	3.3
8	35	31.10	6.67	21.4	.76	2.4
9	47	26.40	6.52	24.7	.64	2.4
Pennsylvania:						
1927 [1]	139	28.00	8.36	29.9	.48	1.7
1927	53	27.00	7.54	27.9	.70	2.6
1926	24	28.30	7.92	28.0	1.09	3.9
1925	29	26.10	8.55	32.8	1.07	4.1
Michigan:						
1927	333	29.40	8.77	29.8	.32	1.1
1925	226	24.80	8.11	32.7	.36	1.5
1921	309	18.00	7.75	43.1	.30	1.7
Minnesota:						
1927	489	30.70	8.31	27.1	.25	.8
1926	508	26.13	8.23	31.5	.25	1.0
1924	475	32.77	7.35	22.4	.23	.7
Nebraska:						
1928	174	31.26	8.40	26.9	.43	1.4
1927	172	30.06	7.05	23.5	.36	1.2
1926	123	21.00	10.70	51.0	.65	3.1
1925	130	23.05	8.60	37.3	.51	2.2
1924	154	25.61	7.60	29.7	.41	1.6
1923	234	29.04	8.50	29.3	.37	1.3
California:						
1927	167	27.55	7.68	27.9	.40	1.5
1926	174	28.02	11.33	40.4	.58	2.1
1925	139	29.68	11.02	37.1	.63	2.1
4	32	32.66	13.97	42.8	1.66	5.1
5	43	33.02	9.83	29.8	1.01	3.1
5a	39	26.93	8.73	32.4	.94	3.5

[1] Return from a special list of crop correspondents.

COTTON

REPRESENTATIVENESS

The township and field-aid samples for 1927 and 1928 are shown in Table 16. The straight and weighted averages checked within a few pounds in most of the important cotton States. The greatest differences occurred in the Mississippi samples for 1928. In Mississippi there is a great difference between the yield per acre of cotton

in the so-called Delta section of the State (districts 1 and 4) and in the highland sections. Difficulty in obtaining a sufficient number of reporters in this Delta section means that in years when the Delta has a good crop of cotton, the weighted average is higher than the straight average. Difficulty in obtaining fully representative samples in New Mexico and Arizona means that the weighted average frequently differs considerably from the straight average. In these States, as with other crops, sample-data on cotton yields must be supplemented by other check information.

TABLE 16.—*Cotton: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate
	1,000 acres	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 acres*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Missouri	291	188	189	168	164	188	334	157	157	189	194	210
Virginia	64	210	210	218	217	230	79	264	264	263	281	265
North Carolina	1,728	227	226	227	228	238	1,860	192	192	211	211	215
South Carolina	2,356	139	134	148	142	148	2,361	134	133	145	143	147
Georgia	3,413	153	144	162	156	154	3,728	136	128	140	133	132
Florida	64	114	113	130	129	126	95	107	107	94	98	97
Tennessee	965	172	162	167	168	178	1,107	174	178	178	175	185
Alabama	3,166	171	167	176	177	180	3,534	147	140	145	142	150
Mississippi	3,340	189	196	193	190	194	4,029	153	172	163	170	175
Arkansas	3,048	150	152	135	145	157	3,681	147	151	144	152	162
Louisiana	1,542	165	163	177	178	170	1,990	150	160	160	171	166
Oklahoma	3,601	108	124	131	131	138	4,243	120	121	127	127	136
Texas	16,176	117	119	125	127	129	17,743	137	133	131	131	138
New Mexico	95	316	323	331	361	352	117	292	335	343	362	360
Arizona	139	310	315	373	372	315	200	388	349	436	421	357
California	138	478	478	349	352	340	218	418	418	414	420	378

[1] Crop-reporting district or county averages weighted by acreage.

BIAS

The greatest difficulty encountered in obtaining the average yield per acre of cotton is the presence of a large degree of cash-crop bias in the individual reports. With both the acreage and yield of cotton there is always a marked tendency for crop reporters and others to underestimate acreage, yield, or production, until after the crop leaves the farmers' hands. Table 17 shows the comparison of the reported yields per acre of cotton lint from both the township and field-aid lists for three successive months during the season of harvest—October, November, and December—and the returns from an inquiry sent out in March after a large proportion of the cotton has left farmers' hands.

TABLE 17.—*Cotton lint: Weighted averages of yields per acre reported by crop correspondents and the official estimate, by States and by months, crops of 1927 and 1928*

State and list	Crop of 1927 as reported in—					Crop of 1928 as reported in—				
	October,[1] 1927	November, 1927	December, 1927	March 1928	Final	October,[1] 1928	November, 1928	December, 1928	March 1929	Final
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Missouri:										
Township	174	151	189	204	------	176	162	157	186	------
Field aid	148	168	164	219	------	185	189	194	230	------
Estimate	------	------	------	------	188	------	------	------	------	210
Virginia:										
Township	199	230	210	257	------	237	248	264	302	------
Field aid	231	247	217	237	------	227	211	281	279	------
Estimate	------	------	------	------	230	------	------	------	------	265
North Carolina:										
Township	189	200	226	251	------	187	195	192	216	------
Field aid	196	206	228	258	------	195	194	211	240	------
Estimate	------	------	------	------	238	------	------	------	------	215
South Carolina:										
Township	113	116	134	165	------	132	126	133	147	------
Field aid	124	129	142	157	------	135	127	143	162	------
Estimate	------	------	------	------	148	------	------	------	------	147
Georgia:										
Township	127	137	144	168	------	117	117	128	141	------
Field aid	135	146	156	178	------	115	117	133	146	------
Estimate	------	------	------	------	154	------	------	------	------	132
Florida:										
Township	141	113	113	148	------	80	109	107	103	------
Field aid	123	145	129	187	------	91	95	98	98	------
Estimate	------	------	------	------	126	------	------	------	------	97
Tennessee:										
Township	131	151	162	184	------	138	146	178	195	------
Field aid	135	158	168	194	------	136	142	175	188	------
Estimate	------	------	------	------	178	------	------	------	------	185
Alabama:										
Township	147	154	167	191	------	114	126	140	157	------
Field aid	142	158	179	203	------	125	127	142	166	------
Estimate	------	------	------	------	180	------	------	------	------	150
Mississippi:										
Township	153	170	196	222	------	144	158	172	191	------
Field aid	165	174	190	224	------	139	149	170	192	------
Estimate	------	------	------	------	194	------	------	------	------	175
Arkansas:										
Township	135	146	152	179	------	130	138	151	169	------
Field aid	130	131	145	169	------	131	141	152	165	------
Estimate	------	------	------	------	157	------	------	------	------	162
Louisiana:										
Township	132	149	163	183	------	130	143	160	178	------
Field aid	148	158	178	205	------	133	154	171	187	------
Estimate	------	------	------	------	170	------	------	------	------	166
Oklahoma:										
Township	97	113	124	139	------	99	108	121	138	------
Field aid	101	114	131	148	------	99	109	127	144	------
Estimate	------	------	------	------	138	------	------	------	------	136
Texas:										
Township	109	112	119	132	------	117	128	133	142	------
Field aid	110	114	127	139	------	117	128	131	145	------
Estimate	------	------	------	------	129	------	------	------	------	138
New Mexico:										
Township	329	288	323	479	------	240	385	335	------	------
Field aid	352	382	361	387	------	350	364	362	378	------
Estimate	------	------	------	------	352	------	------	------	------	360
Arizona:										
Township	405	343	315	379	------	291	329	349	------	------
Field aid	------	318	372	------	------	397	402	421	421	------
Estimate	------	------	------	------	315	------	------	------	------	357
California:										
Township	366	358	478	380	------	309	326	418	346	------
Field aid	371	378	352	440	------	352	402	420	520	------
Estimate	------	------	------	------	340	------	------	------	------	378
United States:										
Estimate	------	------	------	------	154.5	------	------	------	------	152.9

[1] Probable yield as reported on Oct. 1.

One might expect a low probable yield to be reported on the first of October, when the crop has not been harvested to any appreciable extent, as in most of the States there is always a possibility that bad weather will prevent or retard the picking and maturing of cotton after that date. In practically all States in which cotton is an important crop the reported yields were higher for each successive inquiry, the highest being reported in March of the following year. It is possible that the crop reporter overestimates the yield in March, for that is the time of the year when farmers, obtaining credit for the next year's crop, are inclined to be optimistic concerning their ability to grow cotton. This optimism may result in reporting yields somewhat above the facts.

Fortunately there is a better check on the production of cotton than of any other crop; the cotton ginnings are ascertained through periodic personal visits to gins by special agents of the Bureau of the Census. Although it is known that there is a large degree of bias in sample data on both cotton acreage and cotton yield, it is extremely difficult to determine just how much of this bias occurs in the yield reports and how much in the acreage reports. Development of more refined methods of determining acreage changes will make it possible to solve this problem.

PRECISION OF THE SAMPLE AVERAGES

The weighted averages from the township and the field-aid samples checked fully as well as in the case of other major crops in 1927 and 1928. The greatest differences between these two samples occur in the less important cotton States, Missouri, Virginia, and Florida, and in the far Western States, where conditions are extremely variable or the sample is very small. No increase in the number of reports is likely to change materially the averages obtained from the present lists of crop reporters. The matter of bias can not be corrected by increasing the size of sample.

Table 18 presents for comparison (1) the size of cotton yield-per-acre samples, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield obtained for several States. Samples of cotton yield show greater dispersion than do most other samples of yield per acre. The coefficient of variation is seldom less than 35 per cent, and in a State like Oklahoma, in 1927, the coefficient of variation was 80 per cent. The probable error of cotton-yield samples was usually below 2 pounds in Mississippi, Georgia, and Texas for the years studied. The probable error exceeded 3 pounds in South Carolina, where the sample is smaller than in most States. The relative probable error was about 1 per cent in Georgia, but was more than 2 per cent in some of the other States, depending largely on the size of the sample.

The crop reporting district method of stratifying cotton yields materially reduced the probable error of the resulting weighted averages. The district samples showed, on an average, smaller standard deviations than did the sample for the State as a whole. In Oklahoma, for example, the standard deviation for the State in 1927 was 93 pounds, whereas four of the district samples showed a standard deviation of less than 50 pounds.

TABLE 18.—*Cotton: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield or mean	Relative probable error
Georgia:	*Number*	*Pounds*	*Pounds*	*Per cent*	*Pounds*	*Per cent*
1927 [1]	664	166	65.00	39.2	1.70	1.0
1927 [2]	759	154	60.20	39.1	1.47	1.0
1	103	181	53.40	29.5	3.55	2.0
2	119	193	66.70	34.6	4.12	2.1
3	68	159	52.90	33.3	4.32	2.7
4	153	143	51.20	35.8	2.79	2.0
5	119	133	53.80	40.5	3.33	2.5
6	54	120	38.80	32.3	3.56	3.0
7	57	148	51.30	34.7	4.65	3.1
8	58	150	57.80	38.5	5.12	3.4
9	28	129	66.40	51.5	8.47	6.6
1927 [3]	568	139	53.10	38.2	1.50	1.1
1926 [2]	474	164	56.50	34.5	1.75	1.1
1	51	171	52.70	30.8	4.98	2.9
2	79	148	49.70	33.6	3.77	2.5
3	52	143	44.70	31.3	4.18	2.9
4	89	176	57.10	32.4	4.08	2.3
5	66	165	59.70	36.2	4.96	3.0
6	35	183	69.40	37.9	7.91	4.3
7	39	166	42.50	25.6	4.59	2.8
8	44	158	46.70	29.6	4.75	3.0
1926 [3]	532	150	54.20	36.1	1.58	1.1
Mississippi:						
1927 [4]	625	223	79.49	35.6	2.14	1.0
1927 [1]	637	196	69.55	35.5	1.86	1.0
1923 [1]	285	73	42.50	58.2	1.70	2.3
Oklahoma:						
1927 [1]	376	116	93.00	80.2	3.24	2.8
3	30	81	38.10	47.0	4.69	5.8
4	39	186	99.60	53.5	10.77	5.8
5	83	87	49.40	56.8	3.66	4.2
6	43	48	42.00	87.5	4.32	9.0
7	94	214	76.50	35.7	5.32	2.5
8	55	49	54.30	110.8	4.94	10.1
9	26	57	47.10	82.6	6.23	10.9
1926 [1]	292	172	85.50	49.7	3.37	2.0
2	18	180	77.50	43.1	12.33	6.8
3	14	137	54.00	39.4	9.74	7.1
4	35	247	90.00	36.4	10.25	4.1
5	59	179	68.10	38.0	5.98	3.3
6	28	107	54.60	51.0	6.96	6.5
7	71	123	75.80	61.6	6.06	4.9
8	51	126	65.40	51.9	6.18	4.9
9	16	86	47.00	54.7	7.93	9.2
1924 [1]	219	177	60.30	34.1	2.75	1.6
1924 [2]	234	170	57.70	33.9	2.54	1.5
South Carolina:						
1927 [1]	257	152	73.60	48.4	3.10	2.0
1926 [1]	117	166	78.20	47.1	4.87	2.9
1925 [1]	99	146	48.00	32.9	3.25	2.2
1924 [1]	132	161	61.10	38.0	3.59	2.2
Alabama:						
1928 [1]	281	149	76.00	51.0	3.06	2.1
1927 [1]	404	175	67.00	38.3	2.25	1.3
Texas:						
1928 [1]	1,245	144	64.94	45.1	1.24	.9
1927 [1]	1,336	127	58.36	46.0	1.08	.9
1926 [1]	567	143	60.12	42.0	1.70	1.2
1925 [1]	540	106	60.78	57.3	1.76	1.7

[1] As reported in December.
[2] As reported in November.
[3] As reported in October.
[4] As reported in March, 1928.

There is probably no crop on which more inquiries are sent out regarding the yield per acre than on cotton. Not only are yields obtained from the regular township and field-aid reporters, but lists of ginners and bankers, and other special lists, are circularized with cotton-yield questionnaires. The final estimate of the yield of cotton per acre is determined in part on the basis of the yield per acre as derived by dividing the production of cotton shown by the ginning reports, by the estimate of acreage harvested in each State. A large degree of cash crop bias makes it almost impossible until after the crop has left the farmer's hands, to secure a sample on yield per acre that can be used as an estimate of the actual yield. Not until a more satisfactory method of estimating acreage changes has been developed will it be possible definitely to measure the bias of the cotton-yield samples.

TOBACCO

Tobacco is grown in rather limited areas. In any one year dispersion in yield per acre of tobacco in a State is due not only to geographic distribution of weather factors, but also to differences in soils on which the tobacco is grown and to the various types of tobacco produced. In Kentucky, for example, six types of tobacco are grown in more or less sharply defined districts, usually referred to as type districts. As a result of this diversity in the factors that determine yield per acre, farmers report tobacco yields that range from 300 to 1,700 pounds or more per acre.

REPRESENTATIVENESS

Table 19 shows the State average yields per acre of tobacco as obtained from the township and the field-aid samples. The straight and weighted averages differed considerably in some of the States in which the production of tobacco is highly localized; in fact, county weights are frequently used in place of district weights with such a highly localized crop as tobacco. Although the difference between the straight and weighted averages in the same sample may amount to anywhere from 1 pound to several hundred pounds, it is necessary to keep in mind that the true average yield of tobacco on a State basis may be anywhere from 500 to 1,400 pounds, depending on the State and on the type of tobacco grown. On the whole, the tobacco samples show no larger differences between straight and weighted averages than do the samples of most other crops of similar acreage. In Table 19 States with acreages less than 10,000 have been included.

TABLE 19.—*Tobacco: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate
	1,000 acres	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 acres*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Massachusetts	7			1,383	1,399	1,223	8			1,411	1,376	1,245
Connecticut	24			1,255	1,193	1,223	25			1,311	1,205	1,190
New York	1	1,239	1,272	1,250		1,200	1	1,080		1,200		1,275
Pennsylvania	34	1,329	1,336	1,330	1,329	1,360	37	1,327	1,335	1,395	1,380	1,340
Ohio	30	851	832	826	828	819	42	733	744	869	859	800
Indiana	8	768	781	758	740	760	14	627	826	820	812	820
Wisconsin	31	1,023	1,025	990	1,010	1,070	37	1,281	1,324	1,215	1,255	1,325
Missouri	4	957	1,435	818	1,010	1,100	4	880	1,157	825	940	1,100
Maryland	32			818	818	818	31			752	739	700
Virginia	177	792	731	732	703	723	181			716	640	600
West Virginia	4	794	794	822	820	775	7			756	752	750
North Carolina	659	692	693	720	708	737	728	627	628	636	632	651
South Carolina	104	677	678	765	756	737	148	542	545	553	549	556
Georgia	82	722	759	734	723	725	122	643	662	673	712	690
Kentucky	290	726	718	705	707	697	388	737	742	756	754	775
Tennessee	88	825	787	776	752	780	109	858	782	736	742	787
Louisiana	1			400		400	1			405		405

[1] Crop-reporting district or county averages weighted by acreage weights.

BIAS

With tobacco, a reliable check on production is obtained through the records of sales and is of material assistance in rectifying not only the estimates of production, but also those of acreage and yield per acre. There is some tendency toward cash-crop bias in some States. Tobacco is such a highly localized crop that in all except the States of largest production the official estimates are more likely to be based on special information obtained by the State statistician from personal contacts with the trade, than on sample data reported by the regular correspondents.

PRECISION OF THE SAMPLE AVERAGES

The methods of handling the yield samples for tobacco vary considerably from one State to another, depending on local conditions. Consequently the averages from the field lists of crop correspondents are not always comparable with the averages from the township lists, and such a comparison is not particularly significant as an indication of the stability of two samples drawn from the same universe, except in the States with the greatest acreage. In 1927 the two weighted averages from the separate samples were 693 and 708 pounds in North Carolina, 718 and 707 pounds in Kentucky, and 731 and 703 pounds in Virginia. In 1928 these averages were 628 and 632 pounds in North Carolina and 742 and 754 pounds in Kentucky. The two lists were merged in Virginia in 1928. These three States have about 70 per cent of the tobacco acreage of this country, whereas the remaining 30 per cent is distributed among 14 other States.

TABLE 20.—*Tobacco: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

State, year, district, and type	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield or mean	Relative probable error
Kentucky:	*Number*	*Pounds*	*Pounds*	*Per cent*	*Pounds*	*Per cent*
1928	246	763	163.6	21.4	7.0	0.9
1927	411	708	184.4	26.0	6.1	.9
1927	452	710	177.3	25.0	5.6	.8
1	79	708	166.0	23.4	12.6	1.8
2	76	717	204.8	28.6	15.8	2.2
3	30	740	160.0	21.6	19.7	2.7
5	88	717	197.0	27.5	14.2	2.0
7	50	738	163.6	22.2	15.6	2.1
7a	64	703	123.8	17.6	10.4	1.5
8	60	677	180.0	26.6	15.7	2.3
Clarksville and Hopkinsville	32	678	131.5	19.4	15.7	2.3
Paducah	44	736	164.0	22.3	16.7	2.3
Henderson	29	734	153.7	20.9	19.2	2.6
Green River	23	691	141.0	20.4	19.8	2.9
One sucker	35	731	116.5	15.9	13.3	1.8
Burley	289	704	164.3	23.3	6.5	.9
1926	461	875	206.2	23.6	6.5	.7
1926	518	870	194.0	22.3	5.7	.7
1	87	936	228.4	24.4	16.5	1.8
2	91	837	191.4	22.9	13.5	1.6
3	32	856	174.8	20.4	20.8	2.4
5	100	903	171.2	19.0	11.5	1.3
7	68	812	154.0	19.0	12.6	1.6
7a	75	868	164.0	18.9	12.8	1.5
8	58	878	174.3	19.9	15.4	1.8
Clarksville and Hopkinsville	34	829	127.5	15.4	14.8	1.8
Paducah	52	788	142.4	18.1	13.2	1.7
Henderson	27	881	172.2	19.5	22.3	2.5
Green River	28	907	146.1	16.1	18.6	2.1
One sucker	39	895	188.0	21.0	20.3	2.3
Burley	338	864	207.8	24.1	7.6	.9
1925	250	753	173.0	23.0	7.4	1.0
Pennsylvania:						
1928	70	1,394	213.1	15.3	17.2	1.2
1927	21	1,330	204.6	15.4	30.1	2.3
1926	16	1,331	299.4	22.5	50.5	3.8
1925	22	1,428	302.1	21.2	43.4	3.0
Virginia:						
1927	113	771	195.0	25.3	12.4	1.6
1926	94	813	296.0	36.4	20.6	2.5
1924	96	794	336.0	42.3	23.1	2.9
1921	83	609	216.0	35.5	16.0	2.6
South Carolina:						
1927	27	759	128.5	16.9	16.7	2.2
1926	27	678	147.5	21.8	19.1	2.8
Georgia:						
1927	136	740	221.0	29.9	12.8	1.7
1927	25	714	156.0	21.8	21.0	2.9
1926	62	771	167.0	21.7	14.3	1.9
1926	25	741	152.0	20.5	20.5	2.8
1925	183	697	204.0	29.3	10.2	1.5
1924	75	748	190.0	25.4	14.8	2.0

Table 20 presents for comparison (1) the size of tobacco yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield obtained for several States. The coefficient of variation in samples of tobacco yield seldom exceeds 30 per cent and in some cases is below 20 per cent. The probable error in a State that has a large sample, like Kentucky, seldom exceeds 6 or 7 pounds for the State as a whole, but in most States the sample of tobacco yields is small, frequently no more than 25 observations; consequently the probable error may range from 10 pounds to as much as 50 pounds. In dealing with a crop like tobacco the relative probable error is undoubtedly the more significant basis for comparison. In Kentucky the relative probable error was usually less than 1 per cent, and even in some of the States with a small sample the relative probable error seldom exceeded 3 per cent.

STRATIFICATION

A comparison of the standard deviation obtained from the crop-reporting districts and the standard deviation obtained from the type-districts shows that there is somewhat less dispersion when the sample is stratified by type districts than by the regular crop-reporting districts. With a highly localized crop, such as tobacco, made up of from one to several types in a given State, there is no question but that a special system of stratification should be used, which would take into consideration types as well as geographic location. Such a method of stratification would tend to improve the precision of the average yield and result in estimates not only more reliable, but far more useful to persons interested in tobacco.

POTATOES

REPRESENTATIVENESS

Potatoes are grown in practically every State, but in many States the acreage is small. The straight and weighted averages of potato samples, as shown in Table 21, checked within 10 bushels in a surprisingly large number of States. Only in an occasional sample of potato yields per acre did these two averages differ by more than 20 bushels; most of these occurred in the far Western States.

TABLE 21.—*Potatoes: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Maine	161	----	----	173	194	232	179	----	----	163	194	220
New Hampshire	12	----	----	146	154	150	12	----	----	131	138	138
Vermont	21	----	----	161	157	155	21	----	----	149	151	142
Massachusetts	14	----	----	102	100	100	15	----	----	112	103	108
Connecticut	15	----	----	100	98	109	17	----	----	122	129	130
New York	270	96	108	92	106	106	284	110	117	104	113	114
New Jersey	57	144	154	140	167	161	57	----	----	163	162	160
Pennsylvania	220	117	113	117	117	120	246	125	126	134	138	130
Ohio	116	105	102	105	105	105	123	104	100	99	97	98
Indiana	53	107	105	96	98	95	61	109	109	104	109	109
Illinois	64	81	82	87	86	84	70	116	114	109	107	110
Michigan	289	84	83	83	81	80	306	115	115	119	119	117
Wisconsin	260	91	91	91	91	92	278	121	117	116	113	115
Minnesota	328	106	102	104	100	101	354	119	117	118	110	110
Iowa	75	84	83	84	84	82	81	134	132	138	138	135
Missouri	68	84	85	81	83	83	85	121	120	115	112	121
North Dakota	113	114	105	112	101	102	141	107	109	103	104	105
South Dakota	60	110	112	116	119	115	67	85	93	84	88	90
Nebraska	84	96	100	102	107	106	105	94	90	97	95	96
Kansas	49	95	97	90	96	110	54	116	125	125	130	140
Maryland	43	----	----	117	122	122	47	----	----	107	115	115
Virginia	130	105	123	106	115	152	151	----	----	100	92	143
West Virginia	52	116	117	110	112	113	60	----	----	130	125	125
North Carolina	72	99	87	88	86	102	95	94	87	84	84	111
South Carolina	29	68	91	74	----	105	36	65	83	71	----	113
Georgia	17	80	78	69	70	77	22	68	69	82	----	76
Kentucky	52	89	90	89	92	91	57	101	99	104	108	105
Tennessee	39	92	92	87	88	88	43	98	100	92	91	95
Alabama	33	81	72	62	65	75	38	82	83	78	78	74
Mississippi	12	78	72	80	77	78	15	87	95	80	85	89
Arkansas	29	76	77	65	61	68	36	77	76	64	61	75
Louisiana	41	65	45	68	61	65	41	88	61	67	63	70
Oklahoma	45	60	65	62	59	65	63	74	72	72	66	80
Texas	35	63	69	56	69	66	39	75	71	53	60	69
Montana	36	148	151	135	136	135	37	112	112	106	112	115
Idaho	115	186	214	218	211	212	116	147	174	167	168	170
Wyoming	17	151	144	142	142	137	21	107	110	113	117	112
Colorado	96	128	145	136	167	150	110	102	134	104	120	122
Utah	22	168	171	157	154	135	23	162	155	185	197	144
Washington	79	152	166	165	198	170	67	126	149	112	113	135
Oregon	52	135	125	116	116	120	52	122	110	132	142	120
California	52	----	----	124	153	153	56	----	----	131	138	138

[1] Crop reporting district or county averages weighted by acreage.

BIAS

In some of the strictly commercial areas there is definite evidence of cash-crop bias. The final estimates of yields per acre of potatoes in Maine are generally many bushels higher than the averages of the combined field-aid and township samples. In Maine, the car-lot shipments of potatoes furnish a valuable basis for determining the total production of potatoes in that State. In Virginia, the official estimates of yield per acre run much higher than do the sample averages. A large part of the potatoes of Virginia are grown in concentrated commercial districts on each side of Chesapeake Bay, and car-lot shipments supply a check on production estimates. There

seems to be less evidence of cash-crop bias in reports from the far Western States or from the Central States of Michigan, Wisconsin, and Minnesota.

PRECISION OF SAMPLE AVERAGES

The weighted averages from the two samples, township and field-aid, checked within 10 bushels in practically all States east of the Rocky Mountains. As might be expected, some rather wide differences were shown in the far Western States. Table 22 presents a comparison of (1) the size of yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield obtained for several States. The coefficient of variation for potato yields was higher than for the yield samples of most other crops. In very few cases did the sample have a dispersion of less than 40 per cent, and frequently the dispersion reached 50 and 60 per cent, and in the State of Washington in 1924 the coefficient of variation was 81 per cent. The probable error in the important potato States was not far from 1 bushel, while in the far Western States Idaho and Washington, it was from 6 to 8 bushels. The relative probable error is a more satisfactory basis for comparison because of the wide difference in yields as between States. The relative probable error of samples of potato yield was not far from 1 per cent in New York, Michigan, and Minnesota, whereas in North Dakota the relative probable error was slightly more than 2 per cent and reached as much as 6 per cent in Washington in 1924.

TABLE 22.—*Potatoes: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
New York:	*Number*	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
1927	1,824	101.50	54.40	53.6	.86	0.8
1925 [1]	1,086	79.00	41.60	52.7	.85	1.1
2	70	70.70	38.00	53.7	3.06	4.3
3	30	71.00	38.20	53.8	4.70	6.6
4	265	73.50	34.60	47.1	1.43	1.9
5	231	74.00	45.10	60.9	2.00	2.7
6	113	59.10	29.10	49.2	1.85	3.1
7	147	87.80	37.40	42.6	2.08	2.4
8	120	80.80	30.60	37.9	1.88	2.3
9	81	92.80	47.30	51.0	3.54	3.8
9a	29	184.10	46.70	25.4	5.84	3.2
1924	745	138.10	55.50	40.2	1.37	1.0
New Jersey:						
1928	211	155.59	59.30	38.1	2.75	1.8
2	47	107.45	52.70	49.0	5.18	4.8
5	81	175.43	57.10	32.5	4.28	2.4
8	83	163.49	49.30	30.2	3.65	2.2
1926	179	144.59	61.40	42.5	3.10	2.1
2	52	135.00	59.60	44.1	5.58	4.1
5	64	154.37	60.70	39.3	5.12	3.3
8	63	142.54	62.20	43.6	5.28	3.7
Pennsylvania:						
1927 [1]	826	125.00	57.08	45.7	1.34	1.1
1927	404	117.00	50.83	43.4	1.71	1.5
1926	342	108.00	42.85	39.7	1.56	1.4
1925	361	121.00	44.20	36.5	1.57	1.3
Montana:						
1927	111	128.28	67.60	52.7	4.33	3.4
1926	144	90.84	29.90	23.0	1.17	1.3

[1] Return from a special list of crop correspondents.

TABLE 22.—*Potatoes: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error—Continued*

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
Idaho:	*Number*	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
1927	94	222.90	82.10	36.8	5.71	2.6
6	27	209.10	55.90	26.7	7.25	3.5
8	40	299.10	74.90	25.0	7.99	2.7
1926	72	205.50	78.85	38.4	6.26	3.0
1925	89	201.70	85.60	42.4	6.12	3.0
6	28	221.40	70.65	31.9	9.01	4.1
8	22	268.20	94.80	35.3	13.63	5.1
Washington:						
1927	135	178.00	111.65	62.7	6.48	3.6
1926	103	145.00	93.35	64.4	6.20	4.3
1925	78	136.00	96.15	70.7	7.34	5.4
1924	83	132.00	106.60	80.8	7.89	6.0
Iowa:						
1927 [2]	714	81.15	39.93	49.2	1.01	1.2
1	103	99.80	39.17	39.2	2.60	2.6
2	85	91.30	35.97	39.4	2.63	2.9
3	63	68.60	36.29	52.9	3.08	4.5
4	83	79.50	36.34	45.7	2.69	3.4
5	137	85.11	44.89	52.7	2.59	3.0
6	60	75.66	35.04	46.3	3.05	4.0
7	79	66.58	35.25	52.9	2.67	4.0
8	48	72.50	36.88	50.9	3.59	5.0
9	56	72.14	38.11	52.8	3.44	4.8
1926	630	76.10	35.80	47.0	.96	1.3
1925	664	56.08	31.01	55.3	.81	1.4
North Dakota:						
1927	483	111.00	45.75	41.2	1.40	1.3
1	86	123.00	49.25	40.0	3.58	2.9
2	48	125.00	45.00	36.0	4.38	3.5
3	94	92.00	32.50	35.3	2.26	2.5
4	47	119.00	50.75	42.6	4.99	4.2
5	23	98.00	40.25	41.1	5.66	5.8
6	37	98.00	26.00	26.5	2.88	2.9
7	46	120.00	55.75	46.5	5.55	4.6
8	49	114.00	51.25	45.0	4.94	4.3
9	53	116.00	38.75	33.4	3.59	3.1
1926	261	75.00	42.25	56.3	1.76	2.3
1923	186	82.50	38.50	46.7	1.90	2.3
1920	184	76.80	38.50	50.1	1.92	2.5
Virginia:						
1927	209	107.00	48.20	45.0	2.25	2.1
1926	153	77.00	39.90	51.8	2.18	2.8
1924	199	89.00	46.40	52.1	2.22	2.5
1921	220	67.00	35.90	53.6	1.63	2.4
Minnesota:						
1927	558	104.17	40.49	38.9	1.16	1.1
1926	546	96.61	42.90	44.4	1.24	1.3
1924	436	136.87	52.03	38.0	1.68	1.2
Illinois:						
1927	188	87.00	41.10	47.2	2.02	2.3
1926	207	85.00	43.00	50.6	2.02	2.4
Michigan:						
1927	562	82.70	35.36	42.8	1.01	1.2
1926	634	122.30	47.54	38.9	1.27	1.0
1925	554	107.00	41.57	38.9	1.19	1.1

[2] As reported in November.

STRATIFICATION

Only about one-half of the districts in the three States for which district data are available—New York, North Dakota, and Iowa—showed smaller standard deviations than the State as a whole. A separation of commercial districts from noncommercial districts would be the most important step toward the stratification of a State into more homogeneous districts, as commercial districts usually have higher yields per acre than do noncommercial districts. To arrange special districts for potatoes would undoubtedly materially improve the homogeneity of the districts, render the sample more representative, and increase the precision of the weighted average for the States.

SWEETPOTATOES

Sweetpotatoes are primarily a southern crop, for in only three northern States—New Jersey, Illinois, and Missouri—are 10,000 acres or more grown. In only a few scattered cases (Table 23) did the straight average of the samples differ from the weighted average by more than 10 bushels, and seldom did the weighted average from the separate samples show a difference of more than 10 or 15 bushels. Throughout the South sweetpotatoes are grown primarily for home use, although there are important commercial districts in such States as New Jersey, Virginia, and Maryland. Generally speaking, however, sweetpotato acreage is fully as well distributed in the Southern States as is the potato acreage in the Northern States.

TABLE 23.—*Sweetpotatoes: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average[1]	Average (arithmetic mean)	Weighted average[1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average[1]	Average (arithmetic mean)	Weighted average[1]	Official estimate
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
New Jersey	15	126	128	128	126	126	15	------	------	130	138	145
Illinois	10	112	97	110	107	103	10	101	101	111	97	98
Missouri	12	110	109	114	------	112	11	112	110	100	------	105
Maryland	11	------	------	132	144	144	10	------	------	144	152	150
Virginia	43	115	134	116	138	135	44	------	------	99	112	144
North Carolina	89	123	114	116	118	114	80	104	101	96	93	98
South Carolina	53	96	98	100	102	100	49	89	92	83	83	86
Georgia	132	81	86	75	76	80	119	85	86	89	86	86
Florida	29	------	------	95	92	92	28	------	------	94	88	88
Kentucky	16	99	99	87	85	93	14	87	88	89	89	89
Tennessee	48	103	104	97	97	98	41	105	103	92	88	95
Alabama	78	93	94	94	100	98	70	109	111	100	100	93
Mississippi	69	111	115	110	112	112	55	110	118	103	107	110
Arkansas	38	116	117	114	115	116	28	104	100	84	83	90
Louisiana	99	101	98	90	102	98	74	104	91	93	90	90
Oklahoma	23	116	109	108	106	106	20	89	90	90	89	89
Texas	133	94	102	88	96	90	109	84	89	71	73	76
California	12	------	------	121	99	90	12	------	------	129	96	96

[1] Crop-reporting district or county averages weighted by acreage.

Table 24 presents for comparison (1) the size of sweetpotato yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield obtained for the sweetpotato sample for Georgia for four years. The coefficient of variation was high, ranging from 49 to 89 per cent. The relative probable error varied from 1.4 to 2.3 per cent. Georgia is probably a typical Southern State so far as sweetpotato production is concerned.

TABLE 24.—*Sweetpotatoes: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

State, and year	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
Georgia:	*Number*	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
1927 [1]	538	74.4	36.1	48.5	1.05	1.4
1926	378	85.2	44.4	51.8	1.53	1.8
1925	652	41.1	36.4	88.6	.96	2.3
1924	569	68.6	34.1	49.7	.96	1.4

[1] As reported in November.

TAME HAY

REPRESENTATIVENESS

Tame hay of some kind is grown in every State; even Rhode Island has over 40,000 acres in tame hay and Delaware about 80,000 acres. Table 25 shows a comparison of the averages from the two sources of sample data—yields of tame hay, and illustrates the small differences that exist between straight and weighted averages for a crop grown so uniformly over a State.

TABLE 25.—*All tame hay: Averages of yields per acre computed from reports of crop correspondents, and the official estimates, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate
	1,000 acres	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*1,000 acres*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
Maine	1,247			1.18	1.17	1.22	1,235			1.31	1.34	1.28
New Hampshire	463			1.39	1.38	1.27	459			1.48	1.48	1.41
Vermont	922			1.55	1.56	1.53	914			1.67	1.69	1.62
Massachusetts	466			1.58	1.59	1.45	460			1.61	1.62	1.56
Rhode Island	44			1.50	1.47	1.34	43			1.81	1.78	1.56
Connecticut	359			1.49	1.53	1.46	354			1.86	1.90	1.61
New York	4,850	1.55	1.55	1.51	1.51	1.51	4,597	1.46	1.45	1.45	1.46	1.40
New Jersey	257	1.73	1.72	1.61	1.66	1.79	247			1.57	1.60	1.83
Pennsylvania	3,075	1.58	1.54	1.66	1.67	1.65	2,924	1.58	1.54	1.59	1.59	1.59
Ohio	3,139	1.57	1.59	1.56	1.58	1.64	2,780	1.27	1.27	1.25	1.26	1.33
Indiana	2,027	1.43	1.44	1.50	1.50	1.47	1,844	1.28	1.28	1.29	1.28	1.37
Illinois	3,556	1.50	1.46	1.50	1.46	1.49	3,064	1.23	1.20	1.21	1.20	1.32
Michigan	3,036	1.44	1.44	1.46	1.47	1.56	2,832	1.33	1.34	1.35	1.37	1.51
Wisconsin	3,444	1.87	1.87	1.90	1.91	2.03	3,270	1.48	1.46	1.66	1.67	1.53
Minnesota	2,454	1.86	1.83	1.77	1.76	2.07	2,355	1.56	1.52	1.57	1.53	1.79

[1] Crop reporting district or county averages weighted by acreage.

TABLE 25.—*All tame hay: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*—Con.

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average	Average (arithmetic mean)	Weighted average	Official estimate	Acreage	Average (arithmetic mean)	Weighted average	Average (arithmetic mean)	Weighted average	Official estimate
	1,000 acres	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*1,000 acres*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
Iowa	3,135	1.43	1.42	1.44	1.43	1.66	2,835	1.32	1.31	1.38	1.35	1.51
Missouri	3,553	1.33	1.31	1.31	1.30	1.46	3,299	1.17	1.09	1.12	1.07	1.27
North Dakota	1,040	1.66	1.64	1.60	1.61	1.87	1,063	1.51	1.45	1.49	1.47	1.87
South Dakota	1,105	1.66	1.65	1.65	1.68	2.06	1,086	1.22	1.16	1.10	1.08	1.52
Nebraska	1,727	1.68	1.68	1.79	1.80	2.40	1,550	1.43	1.40	1.41	1.36	2.16
Kansas	1,678	1.87	1.87	1.99	1.99	2.53	1,496	1.75	1.77	1.90	1.90	2.37
Delaware	80	1.90	1.67	1.75	1.73	1.78	81	------	------	1.51	------	1.70
Maryland	443	------	------	1.60	1.58	1.65	430	------	------	1.58	1.57	1.75
Virginia	1,077	1.62	1.59	1.44	1.43	1.37	1,063	1.44	1.44	1.35	1.36	1.37
West Virginia	831	1.51	1.52	1.51	1.49	1.52	814	1.57	1.56	1.49	1.47	1.45
North Carolina	806	.93	------	.94	------	.94	752	[2] 1,958	------	[2] 1,896	------	.98
South Carolina	441	.72	------	.70	------	.80	434	[2] 1,363	------	[2] 1,430	[2] 1,245	.87
Georgia	803	.78	------	.82	.83	.70	792	[2] 1,674	------	.62	.62	.64
Florida	95	------	------	.71	.72	.67	88	------	------	[2] 1,425	[2] 1,424	.73
Kentucky	1,318	1.41	1.39	1.37	1.37	1.42	1,253	1.35	1.30	1.21	1.21	1.31
Tennessee	1,352	1.34	1.33	1.27	1.22	1.30	1,310	1.37	1.37	1.34	1.40	1.36
Alabama	615	1.35	.82	[2] 1,490	[2] 1,500	.84	615	[2] 1,609	------	[2] 1,558	[2] 1,600	.77
Mississippi	491	1.06	------	1.10	1.20	1.21	451	[2] 2,135	------	1.05	1.10	1.25
Arkansas	643	[2] 2,067	1.03	1.04	1.06	1.14	625	[2] 2,106	------	[2] 2,331	[2] 2,467	1.09
Louisiana	278	1.27	------	.94	1.49	1.28	297	[2] 2,062	------	[2] 2,554	[2] 3,180	1.43
Oklahoma	566	1.35	------	1.26	1.21	1.59	576	[2] 2,612	------	[2] 2,193	[2] 2,285	1.46
Texas	629	1.22	------	1.15	1.20	1.19	637	[2] 2,356	------	[2] 2,390	[2] 2,400	1.15
Montana	1,274	1.77	1.83	1.84	1.83	2.12	1,294	1.55	1.62	1.64	1.65	1.98
Idaho	1,014	2.61	2.81	2.89	3.24	3.11	1,047	2.40	2.65	2.65	2.68	2.53
Wyoming	685	1.65	1.62	1.75	2.00	1.78	681	1.44	1.45	1.56	1.59	1.80
Colorado	1,225	1.81	1.83	1.83	1.89	2.17	1,207	1.75	1.74	1.90	1.96	2.07
New Mexico	196	1.48	1.47	1.92	2.09	2.21	186	1.82	1.76	1.83	1.94	2.19
Arizona	192	3.25	3.32	3.00	4.10	3.50	185	3.03	3.69	3.30	3.50	3.77
Utah	567	2.73	2.77	2.85	2.80	2.60	570	2.49	2.49	2.00	2.40	2.46
Nevada	208	2.19	2.38	2.24	2.29	2.38	208	2.31	2.44	3.00	3.00	2.60
Washington	932	2.36	2.55	2.36	2.33	2.49	906	2.07	2.09	2.16	2.17	2.36
Oregon	898	2.35	2.47	2.04	2.11	2.28	905	2.15	2.13	2.02	1.96	2.26
California	1,649	------	------	------	------	3.13	1,654	------	------	------	------	3.09

[2] Pounds per acre.

BIAS

There is no particular reason to expect a cash-crop bias in the case of a crop like tame hay that is largely fed. But there is considerable shrinkage in hay; as a result, the quantity used or sold is never equal in tons to the quantity harvested. Shrinkage and wastage due to field stacking are undoubtedly more serious with hay than with grain crops.

PREVENTABLE ERRORS

The final estimate of the yield per acre of all tame hay was in many cases somewhat different from the indication shown by the sample. This difference is due to the fact that the department's definition of what constitutes tame hay differs in many cases from the definition that the farmer has in mind. Consequently the estimates of the yield of tame hay are derived figures obtained by first building up the estimates of the yield of hay by varieties and then dividing the total production by the total acreage. When an Iowa farmer is asked to report on the average yield of all tame hay in his locality

he seldom includes the high-yielding alfalfa or sweetclover hay, Sudan grass, millet, or other special hay crops in his estimate of the average yield for all tame hay.

PRECISION OF THE SAMPLE AVERAGES

The difference between the weighted averages from the two samples seldom exceeded one-tenth of a ton except in some of the far Western States. The yield samples for several varieties of tame hay, such as timothy and alfalfa, show practically the same degree of stability as was shown for all tame hay in Table 25.

Table 26 presents for comparison (1) the size of tame-hay yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield obtained for several States. Few yield-per-acre samples of tame hay had a coefficient of variation much below 30 per cent or above 40 or 50 per cent. The relative probable errors for most of the State samples analyzed fall between 1 and 2 per cent, with a few less than 1 per cent.

TABLE 26.—*Tame hay and alfalfa: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

TAME HAY

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
New York:	*Number*	*Tons*	*Tons*	*Per cent*	*Tons*	*Per cent*
1927[1]	441	1.51	0.45	29.8	0.01	0.7
2	57	1.53	.47	30.7	.04	2.6
3	25	1.57	.54	34.4	.07	4.5
4	370	1.55	.41	26.5	.01	.6
5	187	1.63	.55	33.7	.03	1.8
6	45	1.31	.38	29.0	.04	3.1
7	152	1.48	.48	32.4	.03	2.0
8	79	1.33	.37	27.8	.03	2.8
9	81	1.48	.50	33.8	.04	2.7
1925	308	1.36	.40	29.4	.02	1.5
Illinois:						
1928	364	1.27	.44	34.6	.02	1.6
1	50	1.27	.43	33.9	.04	3.1
3	41	1.37	.46	33.6	.05	3.6
4	42	1.21	.39	32.2	.04	3.3
4a	47	1.32	.41	31.1	.04	3.0
5	52	1.33	.45	33.8	.04	3.0
6	37	1.25	.59	47.2	.07	5.6
6a	41	1.10	.34	30.9	.04	3.6
7	27	1.34	.34	25.4	.04	3.0
9	27	1.19	.33	27.7	.04	3.4
North Dakota:						
1927	282	1.60	.57	35.6	.02	1.2
1	53	1.60	.65	40.6	.06	3.8
2	28	1.48	.48	32.4	.06	4.1
3	63	1.53	.50	32.6	.04	2.6
4	19	1.39	.48	34.5	.07	5.0
5	22	1.55	.62	40.0	.09	5.8
6	21	1.76	.57	32.4	.08	4.5
7	26	1.63	.50	30.7	.07	4.3
8	21	1.81	.55	30.4	.08	4.4
9	29	1.86	.74	39.8	.09	4.8
1926	212	.93	.48	51.6	.02	2.2
Virginia:						
1927	270	1.47	.48	32.7	.02	1.4
1926	257	1.12	.47	42.0	.02	1.8
1924	253	1.51	.48	31.8	.02	1.3
1921	266	1.06	.47	44.3	.02	1.9

[1] Township and field-aid reports combined.

TABLE 26.—*Tame hay and alfalfa: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*—Continued

TAME HAY—Continued

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
	Number	*Tons*	*Tons*	*Per cent*	*Tons*	*Per cent*
Missouri:						
1927	541	1.32	0.45	34.1	0.01	0.8
1926	391	1.05	.40	38.1	.01	1.0
Pennsylvania:						
1927	362	1.62	.44	27.2	.02	1.2
1926	338	1.27	.42	33.1	.02	1.6
1925	384	1.31	.41	31.3	.01	.8
Ohio: 1928	436	1.27	.42	33.1	.01	.8
Michigan:						
1927	607	1.47	.43	29.3	.01	.7
1925	477	.91	.46	50.5	.01	1.1
1923	479	1.19	.38	31.9	.01	.8
Minnesota:						
1927	459	1.80	.52	28.9	.02	1.1
1926	460	1.15	.57	49.6	.02	1.7
1924	507	1.65	.68	41.2	.02	1.2

ALFALFA

California:						
1927 [2]	277	4.77	1.67	35.0	0.07	1.5
4	34	4.44	1.52	34.2	.18	4.1
5	56	5.29	1.62	30.6	.15	2.8
5a	101	5.08	1.58	31.1	.11	2.2
8	47	5.28	1.82	34.5	.18	3.4
1926	283	4.68	2.00	42.7	.08	1.7
1925	190	4.48	2.03	45.3	.10	2.2
Nebraska:						
1928 [2]	267	2.10	.77	36.7	.03	1.4
1927	320	2.48	.78	31.5	.03	1.2
1926	340	1.84	.85	46.2	.03	1.6
1925	257	2.11	.81	38.3	.03	1.4
1924	274	2.22	.93	41.9	.04	1.8
1923	380	2.59	.71	27.4	.02	0.8

[2] As reported in October.

STRATIFICATION

In none of the three States shown by districts in Table 26 were the standard deviations of districts materially smaller than that of the entire sample. It is doubtful if a more refined method of geographic stratification would materially help the precision of tame-hay averages except perhaps in some of the far Western States. Stratification by varities, however, has greatly improved the representativeness and, consequently, the accuracy of the yield samples.

FLAXSEED

Flaxseed is an important crop in North Dakota, South Dakota, and Minnesota, but it is of very minor importance in the few other States in which it is grown. Table 27 shows that in no case did the straight and weighted averages of yield-per-acre reports of flaxseed differ by more than 1 bushel, and the weighted averages of the township and field-aid samples were within 1 bushel or less of each other in all cases. Records of car-lot shipments of flaxseed are available in North Dakota, South Dakota, Minnesota, and Montana as a check on the production of flaxseed. There is apparently little evidence of cash-crop bias in flaxseed yield samples.

TABLE 27.—*Flaxseed: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Minnesota	757	9.7	9.5	10.0	9.5	9.7	643	8.2	7.7	7.8	7.4	7.6
Iowa	19	11.6	11.8	11.6	12.0	12.0	19	10.4	10.6	10.2	10.2	10.4
North Dakota	1,242	8.8	8.4	8.5	8.0	8.2	1,143	7.3	7.2	7.1	7.1	7.1
South Dakota	594	9.7	9.7	9.9	10.1	10.0	588	5.8	5.4	6.2	6.0	5.8
Kansas	31	5.7	5.5	6.2	6.5	5.5	25	6.6	6.7	7.2	7.2	6.9
Montana	170	10.0	10.1	10.1	9.8	10.2	196	8.7	8.7	8.6	8.1	8.5

[1] Crop-reporting district or county averages weighted by acreage.

Table 28 presents for comparison (1) the size of flaxseed yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield, obtained for several States. The coefficient of variation showed a range from as low as 28 per cent in Minnesota in 1924, when the yield was about 11 bushels per acre, to 63 per cent in Montana in 1926, when the average yield per acre was only 5 bushels. Relative probable error varied from 1.1 per cent to as high as 5.5 per cent. On the whole, stratification of the sample by crop-reporting districts seemed materially to improve the precision of the average for the State, as the district standard deviations in North Dakota were generally smaller than for the State as a whole.

TABLE 28.—*Flaxseed: Yield per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
	Number	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
Minnesota:						
1927	406	9.97	3.70	37.1	0.12	1.2
1926	423	9.32	3.07	32.9	.10	1.1
1924	299	11.38	3.17	27.9	.12	1.1
Montana:						
1927	63	10.06	2.53	25.1	.21	2.1
3	19	9.74	1.14	11.7	.18	1.8
6	21	9.00	3.11	34.6	.46	5.1
1926	61	5.13	3.23	63.0	.28	5.5
3	31	6.10	3.56	58.4	.43	7.0
6	17	3.24	1.36	42.0	.22	6.8
North Dakota:						
1927	493	9.09	3.21	35.3	.10	1.1
1	83	9.5	2.71	28.5	.20	2.1
2	44	9.3	2.86	30.7	.29	3.1
3	94	5.9	2.69	45.6	.19	3.2
4	52	10.0	2.50	25.0	.23	2.0
5	26	7.5	2.24	29.9	.30	4.0
6	42	6.9	2.28	33.0	.24	3.5
7	46	10.4	2.69	25.8	.27	2.6
8	48	11.1	3.06	27.6	.30	2.7
9	58	8.1	2.79	34.4	.25	3.0
1926	277	5.68	3.30	58.1	.13	2.3
1	45	5.2	2.40	46.2	.24	4.6
2	24	5.3	2.76	52.1	.38	7.2
3	49	7.6	2.82	37.1	.27	3.6
4	28	2.9	1.56	53.8	.20	6.9
5	26	5.4	1.86	34.4	.25	4.6
6	33	6.5	2.74	42.2	.32	4.9
7	24	3.7	1.50	40.5	.21	5.7
8	20	2.1	1.02	48.6	.15	7.1
9	28	4.3	2.00	46.5	.26	6.0
1923	196	8.28	2.84	34.3	.14	1.7
1920	181	5.88	2.96	50.3	.15	2.6

BUCKWHEAT

Buckwheat is a crop of minor importance in all of the States in which it is grown. Only in New York and Pennsylvania were as much as 200,000 acres grown in 1927. Remarkably little difference exists between the straight and weighted averages computed from reports of crop correspondents (Table 29) for a crop no more important than buckwheat. The weighted averages from the two samples checked closely considering the scattered acreage of the crop.

TABLE 29.—*Buckwheat: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Maine	14	------	------	24.0	27.9	23.0	13	------	------	25.5	26.0	23.0
New York	201	21.3	21.3	20.6	21.0	21.0	192	18.0	17.8	17.9	17.8	18.1
Pennsylvania	210	23.5	23.3	22.5	22.7	23.5	195	19.2	19.0	20.0	19.9	19.5
Ohio	28	20.6	21.1	21.8	21.0	21.0	35	18.3	18.5	22.2	22.0	20.0
Indiana	15	17.4	17.6	16.0	------	17.0	15	17.1	17.1	13.8	14.3	15.0
Michigan	53	13.6	13.6	13.9	12.9	13.0	48	15.5	15.6	15.1	14.4	15.0
Wisconsin	23	16.6	16.2	16.8	16.4	16.6	25	15.1	14.5	17.4	16.3	16.5
Minnesota	126	14.0	11.8	14.9	14.3	14.0	88	13.2	12.5	12.1	------	12.2
Iowa	15	14.3	14.0	16.0	15.6	13.0	6	15.7	16.0	15.4	14.0	14.5
North Dakota	11	14.8	13.9	15.5	------	14.5	10	15.5	14.9	14.3	------	14.5
South Dakota	18	16.1	18.6	15.6	14.8	15.5	19	14.7	14.3	13.9	14.6	14.5
Virginia	14	19.4	19.7	22.9	22.5	21.0	17	------	------	19.5	19.2	19.2
West Virginia	39	22.0	22.5	21.9	22.1	22.0	40	------	------	19.5	20.0	20.0
North Carolina	10	------	------	------	------	20.0	10	------	------	------	------	19.0
Kentucky	9	16.4	15.3	17.0	16.8	16.0	14	18.2	18.6	17.3	16.2	17.0

[1] Crop-reporting district or county averages weighted by acreage.

Table 30 presents for comparisons (1) the size of buckwheat yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield obtained for several States. The coefficient of variation for New York and Pennsylvania ranged from 24 to 34 per cent, whereas in Michigan it was 40 to 56 per cent. The relative probable error in New York State was 1 per cent or less, in Pennsylvania less than 2 per cent, and in Michigan between 2 and 3 per cent.

TABLE 30.—*Buckwheat, field beans, and peanuts: Yields per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

BUCKWHEAT

State and year	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
New York:	*Number*	*Bushels*	*Bushels*	*Per cent*	*Bushels*	*Per cent*
1927 [1]	237	20.6	4.90	23.8	0.21	1.0
1927 [1 2]	771	20.8	5.90	28.4	.14	.7
Pennsylvania:						
1927 [2]	460	24.2	6.40	26.4	.20	.8
1927	215	22.5	5.78	25.7	.27	1.2
1926	193	20.4	6.11	30.0	.30	1.5
1925	219	23.5	7.99	34.0	.36	1.5
Michigan:						
1927	166	13.8	7.69	55.7	.40	2.9
1926	177	15.2	6.10	40.1	.31	2.0
1925	176	14.3	6.15	43.0	.31	2.2

FIELD BEANS

New York:						
1927 [1 3]	61	13.1	3.20	24.4	0.28	2.1
1927 [1]	375	13.1	3.90	29.8	.14	1.1
1927 [4]	115	13.9	4.40	31.7	.28	2.0
1926 [3 5]	161	14.0	5.00	35.7	.27	1.9
1925 [1]	376	11.3	4.80	42.5	.17	1.5
Michigan: [1 2]						
1927	386	8.6	2.87	33.4	.10	1.2
1925	381	13.6	4.22	31.0	.15	1.1
1924	196	11.1	3.85	34.7	.19	1.7

PEANUTS

Virginia:						
1927	35	8.9	1.98	22.2	0.23	2.6
1926	38	12.1	2.56	21.2	.28	2.3
Georgia: [1]		*Pounds*	*Pounds*		*Pounds*	
1927	237	725.0	328.0	45.2	14.38	2.0
1926	146	592.0	260.0	43.9	14.52	2.5
1925	274	478.0	288.0	60.3	11.74	2.5
1924	239	634.0	251.0	39.6	10.95	1.7

[1] As reported in November.
[2] Return from a special list of crop correspondents.
[3] Return from a special list of commercial correspondents.
[4] As reported in October.
[5] As reported in January.

FIELD BEANS

The estimates of bean production, acreage, and yield per acre, are based primarily on sample data from the field aids and from observations made by the field statisticians; consequently there is no opportunity to compare the samples from the two sources as was done with other crops. Table 31 shows both straight and weighted averages from the field-aid sample. The straight and weighted averages checked as closely as in the case of most other seed or grain crops. In most States car-lot shipments of beans are available as a check on the production. There is a possibility of cash-crop bias in the estimates of farmers concerning the yield of beans per acre, but in the two years under consideration there is little evidence that cash-crop bias was allowed for in the making of the estimates of yield per acre.

TABLE 31.—*Field beans: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927				1928			
	Acreage	Reported by the field-aid list [1]		Official estimate	Acreage	Reported by the field-aid list [1]		Official estimate
		Average (arithmetic mean)	Weighted average [2]			Average (arithmetic mean)	Weighted average [2]	
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*
New York	75	13.6	13.2	13.0	80	14.7	14.5	14.5
Michigan	566	8.5	8.8	8.5	538	12.5	10.8	11.0
Montana	32	18.2	17.5	20.0	43			14.5
Idaho	72	23.7	21.7	23.7	82	20.7	18.4	19.0
Wyoming	17	20.1	20.3	18.0	24	15.9		15.0
Colorado	281	6.8	6.0	5.5	309	4.1	4.7	4.5
New Mexico	195	7.0	6.6	5.0	214	5.7	6.6	4.0
California	296	17.0	17.5	16.3	250	20.3	19.7	17.3

[1] Reports received only from field aids.
[2] Crop-reporting district or county averages weighted by acreage.

Table 30 presents for comparison (1) the size of field beans yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield obtained for New York and Michigan. The coefficient of variation fell within a range of 24 to 42 per cent, and the relative probable error was between 1 and 2 per cent in practically all cases.

PEANUTS

Concentration of the peanut acreage in limited areas of commercial production necessitates careful weighting of district or county averages if a representative average for the State is to be obtained. There is considerable difference between the straight and weighted averages from the same sample as well as between the weighted averages of the two samples, largely because of the localization of the crop. (Table 32.) Since peanuts are a cash crop in the commercial districts, a cash-crop bias must be guarded against by the statistician. A later inquiry than that on November 1 is frequently necessary if the yield per acre of peanuts is to be accurately determined. Peanuts are such a specialized and highly localized crop that special inquiries and field travel by the State statistician are necessary to supplement the regular field-aid and township returns.

Table 30 presents for comparison (1) the size of peanut yield-per-acre sample, (2) the average yield, (3) dispersion, (4) variation, and (5) probable error of the average yield obtained for samples from two important States—Virginia and Georgia. The coefficient of variation in Virginia was only about 22 per cent, whereas in Georgia it varied from 40 to 60 per cent. The relative probable error was between 2 and 3 per cent in both States for most years. The large dispersion in Georgia was practically offset by samples several times larger than those obtained in Virginia.

TABLE 32.—*Peanuts: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate
	1,000 acres	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 acres*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Virginia	152	------	------	840	881	810	152	------	------	840	------	910
North Carolina	211	994	1,011	1,058	1,050	954	195	1,023	993	1,014	1,097	950
South Carolina	11	808	757	996	954	775	10	680	748	731	656	690
Georgia	304	765	733	732	758	725	350	597	602	538	542	540
Florida	44	------	------	654	641	640	44	------	------	608	599	575
Tennessee	20	------	------	990	------	850	18	------	------	756	------	800
Alabama	230	675	738	655	650	680	210	598	624	612	675	560
Mississippi	9	714	692	756	747	725	10	589	597	602	604	500
Arkansas	11	758	782	901	838	800	12	675	720	736	740	720
Louisiana	13	543	623	684	636	625	12	532	527	374	338	450
Oklahoma	20	734	------	783	856	800	47	695	------	768	783	750
Texas	117	661	642	706	719	600	120	767	780	647	623	650

[1] Crop-reporting district or county averages weighted by acreage.

RICE

Rice is a highly specialized and localized crop; it is grown in quantity only in Arkansas, Louisiana, Texas, and California. Special inquiries addressed to rice mills, and field travel by the State statistician, are necessary to obtain an adequate estimate of the yield per acre of such a specialized crop as rice. (Table 33.) The differences between straight and weighted averages in the same sample are likely to be somewhat large because of the extreme localization of the crop, and small samples must necessarily be supplemented by the first-hand information of the State statistician. Fairly adequate checks on production are obtained from the mills and cooperative associations that handle the bulk of the rice crop.

TABLE 33.—*Rice: Averages of yields per acre computed from reports of crop correspondents, and the official estimate, by States, 1927 and 1928*

State	1927						1928					
		Reported by the township list		Reported by the field-aid list				Reported by the township list		Reported by the field-aid list		
	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate	Acreage	Average (arithmetic mean)	Weighted average [1]	Average (arithmetic mean)	Weighted average [1]	Official estimate
	1,000 acres	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*1,000 acres*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Arkansas	175	48.5	47.0	51.5	43.5	44.0	164	50.8	49.1	49.7	48.0	47.0
Louisiana	500	35.0	35.4	37.5	34.7	40.0	484	33.4	34.6	36.0	34.2	38.0
Texas	174	49.2	46.0	41.0	39.0	46.2	174	27.7	27.0	43.0	43.4	42.0
California	160	------	------	59.0	54.3	56.0	133	------	------	62.1	63.3	60.7

[1] Crop reporting district or county averages weighted by acreage.

OTHER MINOR CROPS

Table 34 presents for comparison with respect to Danish cabbage in New York, cowpeas in South Carolina, sugar beets in Michigan, and sorghum sirup in three States (1) the size of sample (2) the average yield (3) dispersion, (4) variation and (5) probable error of the average for yield samples. The samples of cabbage yield in New York showed a coefficient of variation between 33 and 46 per cent and a relative probable error of 1 to 2 per cent. The cowpea samples in South Carolina had rather wide dispersion, with coefficients of variation varying from 47 to 95 per cent. With the small size of sample that occurs in a small State like South Carolina, the relative probable error was necessarily large in the case of crops that show such wide dispersion in yields as do cowpeas.

TABLE 34.—*Danish cabbage, sugar beets, cowpeas, and sorghum sirup: Yield per acre. Selected illustrations of size of sample, measures of dispersion, and probable error*

DANISH CABBAGE

State, year, and district	Reports	Average yield (arithmetic mean)	Standard deviation of reported yields	Coefficient of variation	Probable error of the average yield, or mean	Relative probable error
New York:	*Number*	*Tons*	*Tons*	*Per cent*	*Tons*	*Per cent*
1927 [1]	363	10.8	3.6	33.3	0.13	1.2
1927 [2]	140	10.5	4.0	38.1	.23	2.2
1925	367	9.4	4.3	45.7	.15	1.6

COWPEAS

South Carolina:		*Bushels*	*Bushels*		*Bushels*	
1927	102	10.0	5.08	50.8	0.34	3.4
1926	64	9.2	4.33	47.1	.37	4.0
1925	20	5.8	5.52	95.2	.83	14.3
1924	40	6.9	4.16	60.3	.44	6.4

SUGAR BEETS

Michigan:		*Tons*	*Tons*		*Tons*	
1927	60	7.9	2.47	31.3	0.21	2.7
1926	60	9.0	2.37	26.3	.21	2.3

SORGHUM SIRUP [1]

Mississippi:		*Gallons*	*Gallons*		*Gallons*	
1927	254	86.2	42.4	49.2	1.79	2.1
1926	390	110.3	55.3	50.1	1.89	1.7
Georgia:						
1927	285	83.0	38.6	46.5	1.54	1.9
1926	292	74.9	48.0	64.1	1.89	2.5
1925	362	46.4	37.5	80.8	1.33	2.9
1924	339	68.7	35.7	52.0	1.31	1.9
Florida:						
1928 [2]	74	89.2	56.71	63.6	4.45	5.0
1927 [2]	94	90.7	50.78	56.0	3.53	3.9
1926	73	96.6	42.96	44.5	3.39	3.5

[1] As reported in November. [2] As reported in October.

Sugar-beet yields in Michigan had a small degree of dispersion as the coefficients of variation were 26 per cent one year and 31 per cent the other, and the relative probable error was between 2 and 3 per cent. The yield per acre of sugar beets is ascertained from reports from the sugar-beet factories as well as from crop correspondents.

Yields of sorghum sirup show rather wide variability, but are subject to only moderate errors whenever large samples can be obtained.

DISPERSION OF YIELD SAMPLES

The approximate ranges in dispersion of the observations in the yield samples for the more important crops in States east of the Rocky Mountains are presented in summary form in Table 35. The minimum limit of dispersion for these yield samples, as measured by the coefficient of variation, was usually between 20 and 30 per cent. In tobacco samples, however, it was as low as 15 per cent and in potato and cotton samples it exceeded 30 per cent. In samples of two crops —flaxseed and tame hay—it was 30 per cent. The modal minimum variation for these crops was 25 per cent. Winter wheat, spring wheat, rye, buckwheat, and field beans were included in the group with a minimum coefficient of variation of about 25 per cent. Corn, oats, and barley had less dispersion than the modal group.

The maximum limit of dispersion was usually between 45 and 55 per cent. The lowest was 40 per cent, for tobacco, and the highest was 80 per cent, for cotton. In the modal group which included spring wheat, rye, flaxseed, potatoes, and buckwheat, it was 55 per cent; in corn, oats, and field bean samples, which were below the modal group, it was about 45 per cent. The maximum variation for winter wheat, barley, and tame hay was 50 per cent.

TABLE 35.—*Comparison*[1] *of the dispersion and probable errors for the yield estimates of several crops*

Crop	Dispersion				Probable error of the average yields			
	Standard deviation		Coefficient of variation		Probable error		Relative Probable error	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
	Bushels	*Bushels*	*Per cent*	*Per cent*	*Bushels*	*Bushels*	*Per cent*	*Per cent*
Winter wheat	3.5	6.0	25	50	0.15	0.20	0.8	1.5
Spring wheat	2.5	5.5	25	55	.15	.20	.8	2.0
Rye	4.0	6.0	25	55	.20	.40	1.0	4.0
Corn	6.0	11.0	20	45	.18	.45	.5	1.5
Oats	8.0	10.0	22	45	.20	.35	.5	1.5
Barley	7.5	9.0	22	50	.20	.60	.7	2.5
Flaxseed	3.0	4.0	30	55	.10	.20	1.1	2.5
Buckwheat	5.0	8.0	25	55	.15	.40	.7	3.0
Field beans	3.0	5.0	25	45	.10	.30	1.1	2.0
Potatoes	40.0	60.0	38	55	1.00	2.00	.8	2.5
	Pounds	*Pounds*			*Pounds*	*Pounds*		
Cotton	50	80	35	80	1.5	5.0	1.0	2.0
Tobacco	150	300	15	40	5.0	20.0	.7	3.0
	Tons	*Tons*			*Tons*	*Tons*		
Tame hay	.40	.60	30	50	.01	.02	.7	2.0

[1] These values are only approximations of the minimum and maximum limits which include from 80 to 90 of the samples for a given crop; samples from the far Western States are not included.

From this study it might be possible to array or rank these crops in order on the basis of the variation shown by the yield samples. To-

bacco samples could be given first place as having the least dispersion and cotton last as having the greatest. Corn would be second, oats, third, barley and field beans would rank in fourth place, winter wheat fifth, spring wheat, rye, tame hay, and buckwheat would tie for sixth, flaxseed seventh, potatoes eighth, and cotton ninth or last. Of the crops not included in Table 35, for which only a very few samples were studied, sweetpotatoes in Georgia showed greater dispersion than did cotton, and cowpeas in South Carolina showed greater dispersion than either cotton or sweetpotatoes. Yield samples of cabbage, sugar beets, and peanuts had no more than the average degree of dispersion indicated for the more important crops.

COMPARISON WITH OTHER SAMPLE DATA

The dispersion of crop-yield samples is from two to three times as large as is the dispersion of farm-price samples, which vary from as low as 5 to 10 per cent with the farm prices for surplus farm products of corn, hogs, wheat, and cotton, to as much as 30 to 40 per cent with apples (*14*).

Samples of farm-wage data have a dispersion about equal to those of some of the grain crops or from 25 to 40 per cent. Samples of land values vary from as low as 25 per cent dispersion in a homogeneous State with few large cities, like Iowa, to 90 per cent or more in States that include large cities like New York or States in which there are great differences in value between improved and unimproved land as in some of the far Western States. On the other hand, yield samples usually have much less dispersion than have individual farm samples of either acreages or numbers of livestock, which seldom have a coefficient of variation of less than 60 or 70 per cent and frequently exceed 200 per cent.[11]

PROBABLE ERRORS OF THE AVERAGES OF YIELD SAMPLES

Table 35 also presents the approximate range in the probable errors of the averages of yield samples for some of the more important crops in States east of the Rocky Mountains. The samples of crop yields are so large for important and universally grown crops in the more important producing States that the minimum relative probable error seldom exceeded 1 per cent. For corn and oats it was 0.5 per cent, for tame hay, barley, buckwheat, and tobacco it was 0.7 per cent, and the highest minimum was 1.1 per cent, for flaxseed and field beans. The maximum relative probable error was about 1.5 per cent for corn, oats, and winter wheat, 2 per cent for spring wheat, cotton, and field beans, 2.5 per cent for barley, flaxseed, and potatoes, about 3 per cent for tobacco and buckwheat, and 4 per cent for rye.

A comparison of the relative probable errors between different crops is much less satisfactory than a comparison of the coefficients of variation. The relative probable error is necessarily large when only a small acreage of a crop is grown in a State and the reports from crop reporters are few in number. The relative probable error varies directly as the size of the coefficients of variation and inversely as the square root of the number of reports. Rye yields have about the same dispersion as other grain crops in most States, but the sample is

[11] These figures of coefficient of variation are from unpublished studies made by the author and other workers in the Division of Crop and Livestock Estimates. See article by A. J. Beyleveld (*1*).

usually so small that the relative probable error is likely to be very large. If a rye yield sample for a given State has the minimum variation of about 25 per cent, then about 284 reports are sufficient to result in a relative probable error of about 1 per cent. On the other hand, if the maximum variation of 55 per cent occurs, a sample made up of 1,376 reports would be required if the relative probable error is not to exceed 1 per cent.

The relative probable errors of the official estimates are much smaller than those for the individual samples that have been analyzed, as two or more samples of about the same size as the one studied usually form the basis of the official estimates. Stratification of the sample also tends to reduce the size of the relative probable error below that computed from these samples on the basis of a sample selected at random. There is always the possibility of bias in the individual observations of highly commercialized cash crops, such as cotton. Check data usually obtainable for these cash crops make it possible to bridge the gap from the biased sample to a fairly close approximation of the true average of the universe from which the sample was drawn.

COMPARISON OF YIELD ESTIMATES OF THE DEPARTMENT OF AGRICULTURE AND YIELDS DERIVED FROM CENSUS DATA

Thus far in this study the adequacy and reliability of the official estimates of the yields per acre of crops have been considered primarily with regard to the application of the principles of sampling. Yields of important crops in the surplus-producing States, as reported by one list of crop correspondents have been compared with those reported by another list of correspondents of similar size, composition, and geographic distribution. Differences between these indications of yield are about what would be expected when the probable errors of the samples are taken into account and when allowance is made for differences in editing the two samples.

Allowance must be made for such consistent and continued downward bias in the sample as is found with cash crops like cotton. Such allowance is made on the basis of past experience in which the sample is compared with check data on yields derived from ginnings, car-lot shipments, and other commercial movements. This method of measuring bias is not entirely satisfactory because the bias of the acreage sample that is also present when production is used as a basis for checking, can not always be allowed for separately. The use of the crop meter in the Southern States has been of great assistance in obtaining an indication, free from bias, of acreage change. After all, the essential thing is, of course, the reliability of the estimates of production, and accurate estimates of yield per acre are only a means to that end. The estimates of yields per acre of cotton, for example, may be carried along from year to year on too low a level and the estimates of acreage on too high a level, while at the same time the estimates of production of cotton may check closely with cotton ginnings.

It is possible, however, to derive a yield-per-acre figure for a State from census data, which could be used as a basis for checking estimates of yields, or the yields obtained by sampling. On first thought it would seem that a yield-per-acre figure obtained by dividing the production of a crop by acreage, as reported by the census, would serve as an excellent check on the reliability of the estimates, or yields

from sample data. But experience has shown several rather serious limitations to the use of census data as an indication of the yield per acre of a given crop, or as an absolute check on the official estimates of yield.

There is the matter of the weight per bushel of small grains and corn. A bushel of specified weight over the entire country is designated on the questionnaires that are sent to crop correspondents, whereas the legal weight of a bushel for a given crop varies as between States. On the other hand the census enumerator obtains his data in terms of bushels, without specification as to weight. A census is usually taken several months to a year after the crop is harvested, and consequently memory bias is a much more serious source of error with census data than with the samples taken soon after harvest.

Memory bias is especially serious in areas of small farms with small acreages where surplus crops are not grown for market. With the lapse of any considerable period of time the farmer tends to report an acreage greater than the acreage from which his production, as he estimates it, was obtained.

Where the reported production of a crop is actually from the acreage of the crop as reported to the census enumerator, the yield per acre derived by dividing the production of a crop by the acreage would be a satisfactory indication of yield per acre for that crop, assuming, of course, equal completeness of enumeration over the entire State. There is always the possibility that the production as reported to the census enumerator includes only that part of the grain crop that was harvested and threshed.

The reported acreage, however, may include either the entire acreage planted to that crop (of which a part might have been abandoned prior to harvest), or some part of the total acreage reported that was not harvested for grain. The longer the period from time of harvest to the time when the enumerator calls on the farmer, the more likely is the farmer to report as the acreage harvested of a given crop the acreage of the field in which it was grown, without deductions for the parts of the field from which no crop was actually harvested. His total production is more than likely to be reported as the quantity actually threshed as shown by the number of bushels on his bill for threshing. The part of the crop used for some other purpose is likely to be omitted because it has been forgotten. The smaller the acreage per farm, the more serious is this source of error.

In spite of the obvious limitations of census data, it is desirable to make a systematic comparison between yields as derived from the census, on the one hand, and, on the other, official estimates made prior to the completion of the enumeration, or the averages of the returns from sample inquiries to crop correspondents. Where the several indications check closely, greater confidence will be warranted in both the census yields and the yields obtained from sample data.

Such a comparison as this supplements the analysis of estimates of crop yields made with regard to the general principles of sampling. It is an attack on the problem of the adequacy and reliability of the official estimates of crop yields per acre from an entirely different angle, one which should not be omitted in a study of this kind. It would be desirable to have a much more detailed explanation of some of the discrepancies which appear when these sample indications and estimates are checked against yields derived from the census, but such a study would exceed the scope of the present bulletin.

TABLE 36.—*Wheat: Yield per acre computed from census data of acreage and production, official estimates of the United States Department of Agriculture, and averages of yield per acre reported by crop correspondents on the county and township lists, by States, for stated years*

Commodity, group of States, and State	1879		1889		1899				1909				1919				1924			
	Official estimates	Census yields	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields
Winter wheat:																				
Northern—	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
New York	15.0	15.7	13.8	18.0	17.8	18.5	18.5	18.7	22.5	21.3	21.0	23.0	21.5	22.0	22.0	19.7	16.5	17.7	18.0	18.6
New Jersey	12.3	12.7	12.2	15.0	14.5	14.9	14.5	14.4	19.8	18.0	17.9	17.8	18.8	18.7	18.0	16.2	17.0	19.4	18.5	18.8
Pennsylvania	15.3	13.5	12.3	16.4	13.3	13.6	13.6	13.6	17.4	16.7	17.0	17.6	15.6	17.3	17.5	16.5	14.1	15.8	16.5	16.3
Ohio	19.5	18.0	14.6	15.7	14.4	14.9	14.2	15.7	14.3	16.1	15.9	16.8	18.1	18.8	19.1	19.9	16.8	16.8	16.8	18.3
Indiana	20.3	18.0	14.7	14.5	10.2	9.8	9.8	12.1	15.3	15.1	15.3	16.3	14.3	14.9	16.0	16.2	15.6	15.1	17.0	16.5
Illinois	18.7	15.9	16.0	16.7	8.8	8.9	10.0	10.8	17.1	18.4	17.4	17.3	16.7	17.1	17.0	17.3	13.2	14.3	14.7	16.0
Michigan	19.2	19.5	14.7	16.5	7.9	8.1	8.4	10.7	18.3	18.8	18.8	20.0	19.4	19.8	20.3	19.3	19.3	19.0	22.0	23.8
Missouri	14.0	12.0	13.0	15.5	10.1	10.7	9.9	11.2	14.1	14.7	14.7	14.8	15.1	13.5	13.5	14.3	12.1	12.0	12.8	13.3
Nebraska	11.3	9.4	12.0	13.2	8.1	8.7	10.3	9.8	18.9	19.6	19.4	17.9	12.3	13.7	14.8	13.5	17.9	17.5	19.5	19.5
Kansas	11.0	9.3	18.4	19.2	9.8	9.5	9.8	10.2	14.5	15.1	14.5	13.0	12.8	14.0	13.0	13.2	15.5	15.5	16.3	15.6
Oklahoma	.....	.....	.....	.....	.....	.....	.....	.....	13.1	13.7	12.8	12.0	13.2	13.7	14.0	14.0	15.9	14.5	16.4	15.5
Texas	7.6	6.9	10.3	12.2	10.2	10.9	11.1	11.9	8.5	11.8	9.1	7.9	14.9	16.6	16.5	15.1	17.7	17.0	18.5	16.1
Southern—																				
Delaware	13.0	13.4	11.6	15.9	11.0	15.6	12.8	15.8	13.2	14.1	14.0	14.8	12.0	12.5	12.0	12.5	16.0	16.9	16.0	17.6
Maryland	14.4	14.1	11.3	16.3	13.6	14.1	14.1	15.2	14.5	13.7	14.5	16.0	13.5	13.9	13.5	14.5	16.5	15.1	15.8	15.8
Virginia	9.2	8.7	8.4	10.7	8.1	8.4	8.4	9.6	11.1	10.5	11.2	11.7	11.5	11.2	11.8	11.6	13.3	13.1	13.1	13.4
West Virginia	13.0	10.2	10.2	10.4	9.0	9.6	9.3	9.7	13.1	13.5	13.0	12.3	14.5	13.8	13.5	12.6	14.0	12.1	13.2	12.3
North Carolina	7.0	5.3	6.2	6.4	6.8	6.8	6.7	5.8	9.5	9.7	9.5	7.6	9.0	9.3	8.5	7.6	10.1	11.4	12.0	11.0
South Carolina	8.4	5.6	6.0	5.7	5.8	6.5	6.5	5.8	9.1	13.5	10.0	7.2	9.5	10.3	9.0	7.5	10.4	13.1	12.0	10.1
Georgia	9.0	6.6	6.3	5.6	6.4	7.1	6.8	5.5	10.2	10.9	10.0	8.1	10.5	10.3	10.5	7.7	10.2	11.0	10.5	8.1
Kentucky	14.0	9.8	11.0	11.9	8.8	9.1	9.1	10.0	11.6	12.4	11.8	12.8	11.3	11.3	11.5	12.4	10.9	10.3	10.0	10.2
Tennessee	8.0	6.1	7.5	9.5	7.2	8.0	8.7	8.4	10.2	10.4	10.4	10.5	10.0	9.3	9.0	9.3	.....	11.2	10.5	10.1
Spring wheat:																				
Minnesota	12.3	11.4	14.6	15.5	13.0	13.4	13.4	14.5	16.5	17.0	16.8	17.4	8.6	9.4	9.3	9.9	18.9	21.8	21.8	22.2
North Dakota	.....	.....	9.4	9.7	12.1	12.1	12.8	13.5	12.6	14.3	13.7	14.3	6.5	6.1	6.9	6.8	15.3	15.2	15.5	14.8
South Dakota	.....	.....	.....	.....	9.9	10.0	10.7	10.5	13.4	14.1	14.1	14.6	9.4	7.6	8.0	8.0	14.7	14.8	14.9	14.2
All wheat: United States	13.8	13.0	12.9	13.9	.....	.....	11.5	12.5	.....	.....	15.8	15.4	.....	.....	14.7	12.9	.....	.....	16.2	15.7

TABLE 37.—*Corn: Yield per acre computed from census data of acreage and production, official estimates of the United States Department of Agriculture, and averages of yield per acre reported by crop correspondents on the county and township lists, by States, for stated years*

State	1879		1889		1899				1909				1919				1924			
	Official estimates	Census yields	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields
	Bush.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
Maine	30.0	31.0	36.0	35.0	35.1	34.2	36.0	38.3	36.5	...	38.0	42.7	50.0	38.4	55.0	41.4	45.0	41.5	42.0	39.7
New Hampshire	32.5	36.9	36.5	41.6	34.1	38.6	39.0	42.1	34.7	...	35.1	46.2	35.1	32.0	50.0	46.3	28.0	42.4	44.0	48.0
Vermont	36.0	36.5	35.0	40.7	42.5	36.0	36.0	38.3	43.1	...	37.0	40.0	46.3	50.3	53.0	44.2	36.7	43.3	47.0	45.2
Massachusetts	36.0	34.2	34.3	39.1	43.8	37.5	36.0	39.4	35.6	...	38.0	48.6	61.1	54.2	60.0	52.4	46.8	43.8	45.0	45.0
Rhode Island	32.0	31.4	31.3	32.5	31.5	43.6	31.0	35.4	30.0	...	33.2	41.1	35.0	43.2	45.0	42.4	36.3	40.5	42.0	40.1
Connecticut	29.0	33.7	31.0	36.4	40.0	39.4	39.0	40.3	45.7	...	41.0	48.0	49.0	45.5	60.0	48.5	38.9	33.9	43.0	39.9
New York	33.0	33.0	29.3	30.6	28.5	29.1	31.0	30.4	30.5	36.1	36.0	35.4	39.6	38.9	43.0	44.0	32.4	37.0	33.0	36.5
New Jersey	34.0	32.4	30.2	32.3	39.2	39.0	39.0	37.2	31.5	36.7	32.7	37.7	37.8	40.8	40.0	37.6	30.0	39.7	34.0	33.2
Pennsylvania	35.0	33.4	29.8	33.8	36.0	36.3	32.0	35.0	32.4	30.4	32.0	30.1	49.0	46.1	47.0	45.6	38.3	36.9	36.0	36.4
Ohio	35.0	34.1	29.6	35.7	36.5	36.2	36.8	39.7	39.6	38.7	39.5	40.2	40.8	43.6	44.0	42.1	27.0	28.8	26.0	27.5
Indiana	33.0	31.4	29.0	30.4	37.1	36.6	38.0	39.8	38.2	38.0	40.0	39.9	35.8	36.2	37.0	35.6	28.2	28.8	25.4	27.8
Illinois	35.0	36.1	32.3	36.8	34.9	34.8	36.0	38.8	34.6	35.8	35.9	38.8	32.7	33.0	35.0	36.1	31.7	34.1	32.0	33.4
Michigan	37.0	35.3	28.5	28.9	31.7	31.7	25.0	29.7	35.4	36.9	35.4	33.3	38.4	39.2	39.0	35.5	29.8	27.1	26.0	28.2
Wisconsin	39.0	33.7	26.3	30.4	33.3	33.5	35.0	35.6	34.2	35.0	33.0	33.7	51.9	42.7	47.0	38.7	28.7	27.2	26.0	25.1
Minnesota	35.0	33.8	28.5	27.4	32.7	31.3	33.0	32.8	34.5	34.9	34.8	33.9	37.7	40.0	40.0	35.6	28.1	30.9	28.0	26.5
Iowa	38.0	41.6	39.5	41.3	34.0	35.6	31.0	39.1	32.3	33.9	31.5	37.1	39.5	39.9	41.6	41.2	30.1	31.6	28.0	28.4
Missouri	37.0	31.2	32.2	32.4	25.8	27.5	26.0	28.1	34.5	26.4	26.4	26.9	26.6	26.0	27.0	26.3	25.0	26.5	26.0	23.5
North Dakota	...	...	...	...	30.4	23.6	23.0	20.6	34.6	34.0	31.0	26.7	30.4	29.1	33.0	20.3	22.6	21.5	20.0	19.2
South Dakota	...	...	...	...	27.2	24.8	26.0	27.1	29.9	30.8	31.7	27.3	30.0	26.2	28.5	25.1	21.6	23.2	22.0	20.6
Nebraska	41.0	40.1	36.5	39.4	27.4	26.8	28.0	28.8	25.8	23.8	24.8	24.8	23.4	24.4	26.2	23.9	24.9	25.4	24.2	21.2
Kansas	33.0	30.9	35.3	35.5	27.3	27.4	27.0	27.8	18.2	19.8	19.9	19.1	14.4	16.3	15.5	16.2	25.1	23.9	25.2	21.0
Delaware	27.0	19.3	17.5	17.7	20.5	27.1	22.0	24.7	16.9	34.0	31.0	25.6	20.0	39.5	30.0	21.6	25.0	31.2	27.0	23.9
Maryland	30.6	24.0	20.6	25.4	27.8	32.0	32.0	30.0	28.5	31.6	31.4	27.7	34.0	41.8	41.0	34.0	36.2	32.9	31.0	27.8
Virginia	19.0	16.5	15.9	17.0	20.5	20.9	20.0	19.2	21.8	23.3	23.2	20.6	25.1	28.6	28.0	23.4	20.6	22.6	21.0	20.8
West Virginia	31.0	24.9	22.4	23.2	26.0	26.0	26.0	22.9	27.4	31.0	31.4	25.3	32.0	37.3	34.0	29.9	25.6	30.3	28.0	23.3
North Carolina	15.0	12.2	12.0	10.9	13.3	13.1	13.0	12.8	15.3	16.7	16.8	13.8	18.5	20.7	19.0	17.7	17.6	18.3	18.0	15.8
South Carolina	7.5	9.0	11.5	10.2	7.8	9.0	9.0	9.8	14.4	16.1	16.7	13.3	15.9	19.3	16.0	15.7	17.2	11.7	11.5	12.1
Georgia	9.3	9.1	11.2	11.3	10.1	10.0	10.0	9.8	13.9	14.7	13.9	11.6	14.8	16.0	14.5	12.1	10.6	12.6	12.2	10.5
Florida	8.5	8.8	10.7	9.8	9.8	10.4	10.0	9.3	12.6	16.1	12.6	11.6	14.1	15.4	15.0	11.2	10.8	13.5	14.5	11.9
Kentucky	32.0	24.1	26.5	26.5	21.6	23.5	21.0	22.3	26.8	27.6	29.0	24.3	22.0	25.6	25.0	22.0	24.0	26.6	25.0	22.8
Tennessee	25.0	21.6	22.0	22.8	18.6	19.5	20.0	19.9	20.4	21.9	22.0	21.5	23.0	25.3	23.0	21.4	21.4	21.9	22.0	21.0
Alabama	13.0	12.4	13.5	14.1	15.5	12.4	12.0	12.8	12.4	14.6	13.5	11.9	15.6	16.2	14.5	13.1	12.8	13.0	13.0	12.0
Mississippi	16.0	13.6	14.8	15.3	15.9	16.1	16.0	17.0	14.4	15.4	14.5	13.1	15.1	17.0	15.0	14.3	10.3	12.0	12.0	12.1
Arkansas	24.0	18.6	20.0	20.6	20.2	19.7	20.0	19.0	15.3	19.2	18.0	16.5	19.6	18.1	18.0	14.9	17.2	17.0	16.5	15.3
Louisiana	15.0	13.3	17.5	15.6	14.9	17.0	18.0	16.4	18.5	23.0	23.0	16.4	17.9	16.7	17.5	14.4	11.5	11.3	11.5	11.1
Oklahoma	...	...	...	...	30.4	26.4	19.0	27.6	16.1	16.1	17.0	15.9	22.7	24.2	24.0	21.8	21.4	20.7	20.5	17.8
Texas	13.0	11.8	18.3	22.4	21.3	22.4	18.0	21.9	14.3	15.9	15.0	14.7	28.8	29.5	30.0	22.8	17.8	17.2	17.0	15.0

Montana					22.8	33.7	23.0	23.0		43.7	35.0	28.8		16.6	13.5	8.5	17.1	18.6	18.0	14.0
Idaho									37.6	34.5	30.6	34.6	26.6	33.2	35.0	27.5	22.8	35.4	35.0	30.7
Wyoming					26.2	22.0	22.0	19.2	25.0		28.0	19.0	12.0	14.6	16.0	10.1	11.2	19.5	14.0	10.5
Colorado			25.4	12.7	15.8	15.6	17.0	15.0	22.6	24.2	24.2	15.0	14.6	22.9	16.7	13.4	13.6	14.3	10.0	9.4
New Mexico			20.0	20.4	25.4	15.3	20.0	16.4	32.4	20.0	31.3	13.5	25.1	24.2	30.0	20.9	23.4	15.3	20.0	13.2
Arizona									32.1	32.1	32.1	19.1	20.0	29.4	33.0	20.1	22.9	20.9	30.0	13.3
Utah			18.3	14.7	22.3	24.3	20.0	21.7	33.3	28.0	31.4	23.4	33.1	27.5	18.0	19.2	30.0	29.4	26.0	22.9
Nevada													24.0	50.0	30.0	26.9	50.0	35.5	27.0	25.0
Washington					15.0	22.5	23.0	20.9	29.5	27.8	27.8	21.6	58.0	29.7	36.0	25.9	31.6	39.5	33.5	29.8
Oregon	32.0	22.5	20.0	19.7	20.0	26.8	22.0	21.2	19.6	31.5	30.7	26.1	30.4	28.3	26.2	26.5	31.7	31.2	30.5	30.2
California	28.0	27.8	28.2	33.9	27.3	31.5	27.0	27.4	34.3	31.8	34.8	24.5					36.4	22.9	35.0	30.7
United States	29.2	28.1	27.0	29.4			25.3	28.1			25.5	25.9			28.6	26.7			23.2	22.2

The indications of yield per acre from the census are available for six years—1879, 1889, 1899, 1909, 1919, and 1924. The yields as reported by the county list of crop reporters and also by the township list are obtainable for only the four years—1899, 1909, 1919, and 1924. The four indications concerning yield per acre (1) those derived from the census, (2) those from the county reporters, (3) those from the township reporters, and (4) the official estimates, for wheat, corn, oats, flaxseed, cotton, and tobacco are shown in Tables 36 to 41, respectively.

This analysis is designed primarily to answer two questions:

(1) How closely do the yields obtained by the methods of sampling used by the department check in an absolute sense with the yields derived from census data? That is, how closely do the yields per acre obtained by the two methods compare when checked directly, one with the other, for a given crop, in a certain State, for a given year?

(2) What degree of correlation is there between the yields per acre derived from census data and the official estimates of yield, as well as between census yields and the two indications from sample data? Although the yield reports by States obtained by one method, might be generally higher than the reports obtained by the other, because of bias in the individual observations of the sample, or to inherent limitations in the census material, either one indication or the other might reflect relative differences as between different States, or as between different years in the same State. The correlation coefficient is used here in its generic sense of measuring the covariation between two variables, both of which are measurements of the same physical phenomena, agricultural yields per acre in given States. No causal relationship between the variables is involved.

This analysis will serve to show also how closely the small sample of county reports, weighted by county weights, compares with the larger sample of township reports, unweighted in 1899 and 1909 and weighted by districts in most cases in 1919 and 1924. The correlation of these two separate indications from sample returns will be of assistance in evaluating the dependability of the county samples of crop yields per acre. This correlation bears directly on the reliability of these estimates of yield made prior to 1896, when returns were first obtained from the township list of crop correspondents, and while the county sample was the chief source and basis of the official estimates of all kinds. Prior to 1882 the samples of reports from county correspondents were the basis of these estimates.

In making the comparisons of yields per acre on an absolute basis, the States are divided into three mutually exclusive categories: (1) States where the yield data from any two sources check within 1 bushel for grain crops, 0.5 bushel for flaxseed, 10 pounds or less for cotton and 50 pounds or less for tobacco, (2) States where the estimates or sample averages of yields are higher by more than these amounts than those derived from census data, and (3) States where estimates or sample averages and of yields are lower by more than these amounts than the census yields. The number of States falling within each of these three categories is then expressed as a percentage of the total number of States involved in the comparison. The sum of these three percentage figures would therefore be 100. A fourth category, not mutually exclusive so far as the other three are con-

cerned, includes the States for which the yield data from any two sources check within 2 bushels or less for grain crops, 1 bushel for flaxseed, 20 pounds or less for cotton, and 100 pounds or less for tobacco. The number of cases falling in this fourth category is expressed as a percentage of the total number of cases included in the comparison.

This analysis shows the percentage of cases in which official estimates of yields per acre and census yields check within 1 bushel for wheat, corn and oats, the percentage of cases in which they check within 2 bushels, and whether there is a tendency for estimates to be higher or lower than the census yields. A similar comparison is made between census yields and yields as reported by the county reporters, and also between census yields and yields reported by reporters on the township lists.

In Table 42 these comparisons are made for all years by geographic groups of States. This makes it possible to differentiate between various sections of the country in drawing conclusions. In Table 43 all States are combined for each given year, thereby making it possible to study each census year separately and to note any changes taking place with the passage of time.

TABLE 38.—*Oats. Yield per acre computed from census data of acreage and production, official estimates of the United States Department of Agriculture, and averages of yield per acre reported by crop correspondents on the county and township lists, by States, for census years, 1879–1924.*

State	1879		1889		1899				1909				1919				1924			
	Official estimates	Census yields	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields
	Bush.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
Maine	30.0	28.8	29.4	30.2	37.0	34.7	35.0	**35.0**	32.3	-------	37.0	35.0	38.8	33.1	34.0	30.9	38.7	37.5	37.0	37.9
New Hampshire	35.0	34.5	**30.5**	**33.5**	32.9	35.1	35.0	**39.5**	37.5	-------	31.5	35.6	35.0	36.5	37.0	33.0	40.0	36.1	39.0	39.4
Vermont	33.0	37.6	31.5	32.6	41.3	36.6	37.0	**37.4**	36.7	-------	32.2	29.9	34.9	35.0	36.0	28.8	39.9	41.2	38.0	34.1
Massachusetts	41.0	31.2	27.2	27.1	34.9	36.6	32.0	36.0	20.0	-------	31.0	33.9	40.0	36.0	38.0	30.2	20.0	34.9	34.0	36.7
Rhode Island	24.0	28.6	26.5	27.6	24.5	25.2	26.0	30.8	25.0	-------	25.0	27.9	-------	31.0	34.0	28.4	22.0	30.0	30.0	36.4
Connecticut	23.0	27.5	25.6	24.3	28.3	---	28.0	32.0	23.1	-------	27.5	26.8	29.7	32.0	31.0	27.1	28.5	31.4	29.0	29.1
New York	31.0	29.8	26.0	27.4	29.1	31.0	31.0	30.7	28.0	28.4	28.2	26.7	24.5	25.5	25.5	23.0	35.8	36.8	36.0	33.2
New Jersey	32.0	27.0	23.6	23.4	26.4	23.9	24.0	21.1	24.7	27.6	25.5	19.1	27.8	29.9	30.0	20.8	30.0	34.9	32.0	**27.2**
Pennsylvania	31.0	27.3	26.2	27.6	33.3	32.5	33.0	31.7	28.7	25.9	26.0	24.6	30.9	28.9	31.0	24.8	33.5	36.6	36.0	**33.7**
Ohio	29.9	31.5	31.3	33.0	35.3	35.5	36.0	37.7	32.7	31.7	32.5	32.2	33.3	31.8	33.5	32.2	37.2	43.5	41.0	**41.0**
Indiana	28.3	25.0	28.2	28.6	33.0	32.8	32.0	34.0	28.2	29.3	30.5	30.3	32.0	31.0	33.0	30.6	37.0	36.6	38.0	**26.3**
Illinois	32.0	32.2	37.5	35.6	37.5	36.9	38.0	39.5	34.1	33.0	36.6	36.0	30.1	28.1	30.0	**30.1**	40.0	38.4	40.0	**39.2**
Michigan	32.2	33.9	32.7	34.0	32.6	34.1	34.0	35.6	29.1	30.2	30.5	30.7	23.7	24.6	25.0	**24.4**	40.0	42.3	42.0	**39.8**
Wisconsin	39.0	34.4	34.5	37.3	**36.4**	34.4	36.0	35.5	36.3	**35.1**	35.0	**33.0**	32.9	32.1	33.4	30.3	38.3	40.0	40.0	**35.5**
Minnesota	35.0	37.9	34.0	31.6	**34.3**	33.6	32.0	33.6	31.8	32.9	33.0	**31.5**	25.9	27.9	**28.0**	**26.0**	41.4	**42.7**	43.0	**41.6**
Iowa	36.0	33.6	36.3	39.1	35.6	35.1	33.0	35.9	26.9	27.8	27.0	**27.5**	**33.8**	32.9	34.6	**34.1**	38.3	41.7	43.0	**39.4**
Missouri	24.6	21.3	25.5	23.7	24.6	26.5	25.0	22.4	25.6	26.5	27.0	**23.1**	**27.0**	27.1	27.0	**23.7**	23.4	25.2	27.5	**20.9**
North Dakota	-	-	18.7	14.3	30.6	**29.5**	30.0	28.3	28.6	32.6	32.0	**30.7**	14.9	14.9	16.0	14.6	31.3	32.7	34.0	**30.1**
South Dakota	-	-	-	-	**26.3**	28.3	26.0	28.1	27.8	30.0	30.0	**28.0**	29.4	27.1	29.0	27.8	36.6	36.6	37.0	**35.2**
Nebraska	32.0	26.2	27.6	29.2	**27.3**	28.0	30.0	30.1	**24.7**	24.9	25.0	22.6	32.6	31.4	32.8	29.5	29.1	31.2	31.0	**26.7**
Kansas	25.0	18.8	26.5	30.5	27.2	30.2	**29.0**	27.2	**27.4**	26.8	28.2	24.6	28.3	28.4	28.1	25.6	26.6	27.2	26.0	**23.0**
Delaware	22.0	22.1	18.3	19.8	15.0	27.8	**20.0**	25.1	**20.0**	20.7	25.5	23.2	20.0	15.0	23.0	14.9	-----	31.4	30.0	**29.4**
Maryland	23.0	17.7	18.7	20.4	22.1	25.9	**23.0**	24.9	25.4	26.6	25.4	23.6	33.8	26.4	28.0	22.2	26.3	35.6	34.0	**29.2**
Virginia	12.0	9.5	13.5	11.5	14.6	14.8	14.0	11.9	18.7	18.9	19.0	14.1	19.5	22.2	22.0	14.4	22.2	25.0	23.5	**19.2**
West Virginia	22.3	15.0	17.2	16.3	23.8	21.9	23.0	18.4	22.0	21.5	22.0	16.7	21.2	25.0	25.0	18.0	24.3	27.2	26.0	**23.1**
North Carolina	16.0	7.7	10.2	8.3	11.4	12.2	12.0	9.1	16.7	15.6	16.5	12.2	19.2	18.5	11.7	13.3	23.4	19.9	18.0	**15.5**
South Carolina	15.0	10.4	10.5	9.8	10.0	12.9	12.0	12.0	17.9	22.7	21.0	17.7	20.8	25.5	23.0	18.4	22.1	21.3	21.4	**20.2**
Georgia	15.0	9.1	11.0	9.2	10.1	11.4	9.0	9.8	20.3	19.5	19.0	15.1	16.8	19.6	20.0	14.7	19.6	18.1	17.0	**14.7**
Florida	16.0	9.8	10.5	9.3	9.8	10.6	9.0	9.5	16.5	18.6	17.0	14.0	15.7	16.2	19.0	12.9	12.0	14.8	15.0	**13.2**
Kentucky	16.8	11.4	18.5	13.6	16.9	18.7	18.0	12.7	18.7	21.6	22.3	13.8	21.7	22.7	22.5	12.2	20.7	23.8	23.2	**19.3**
Tennessee	18.0	10.1	11.5	12.5	14.0	15.4	14.0	11.6	19.7	19.8	20.0	13.8	22.3	22.6	23.0	14.9	20.8	23.4	22.0	**18.3**
Alabama	17.0	9.4	9.5	9.4	10.9	11.7	10.0	8.7	16.4	17.2	16.5	12.6	15.3	19.1	18.0	13.1	19.8	19.4	15.0	**14.5**
Mississippi	11.6	9.9	10.2	10.2	12.2	11.5	10.0	9.9	13.7	16.4	16.0	13.1	16.2	17.6	19.0	14.3	19.7	18.7	18.0	**15.8**
Arkansas	23.2	13.3	16.5	14.5	22.4	18.9	19.0	14.0	20.8	23.0	22.8	16.3	24.1	21.1	22.0	15.6	23.2	21.6	20.0	**18.5**
Louisiana	14.0	8.6	9.4	11.0	18.2	24.1	18.0	11.3	18.6	18.4	20.0	14.1	16.7	19.2	22.0	14.6	22.5	22.3	20.0	**20.6**

Oklahoma										26.3	28.8	29.0	27.3	32.1	32.9	33.0	28.9	26.0	26.2	27.0	22.5
Texas	25.0	20.6	22.7	23.8	25.8	27.8	25.0	28.6	16.2	13.5	18.7	16.0	42.6	40.5	42.0	34.3	33.4	37.6	34.0	29.7		
Montana			30.0	29.1	38.0	39.3	38.0	35.4	51.8		51.3	41.4	15.4	12.7	10.0	13.5	39.6	30.8	29.5	25.9		
Idaho			28.0	26.7	30.3	34.0	34.0	30.2	43.6	45.2	44.5	37.4	27.2	31.9	35.0	21.7	34.3	35.0	36.0	26.3		
Wyoming				26.6	30.4	34.1	30.0	28.4	33.5		35.0	27.1	13.6	15.4	18.0	17.2	29.9	33.4	31.0	23.5		
Colorado			32.0	28.6	33.8	32.1	27.0	25.5	42.3	33.6	38.0	27.7	28.5	32.3	26.2	26.0	37.8	34.4	25.0	25.3		
New Mexico			21.0	20.8	24.2	21.9	24.0	21.6	43.7	33.1	40.0	21.4	22.8	32.1	36.0	27.1	19.3	24.5	24.0	15.6		
Arizona									33.0	33.9	37.0	32.3	35.0	41.2	41.0	31.8		41.5	35.0	22.3		
Utah			25.0	26.3	33.6	36.2	34.0	33.1	43.6		46.1	39.9	45.2	37.2	34.0	27.9	54.1	45.7	40.0	32.8		
Nevada									36.5		40.0	42.7	13.2	30.0	32.0	25.2	30.0	32.8	34.0	30.5		
Washington			31.0	34.9	36.6	42.4	37.0	42.1	42.7	47.4	49.0	49.0	22.9	39.1	40.0	42.1	25.5	39.5	39.5	38.6		
Oregon	36.0	28.9	25.7	27.2	26.6	30.3	30.0	25.7	32.1	34.4	37.8	32.1	26.7	37.5	32.0	29.4	22.7	35.7	31.0	27.8		
California	33.0	26.9	25.0	25.4	33.5	30.7	31.0	32.3	29.4	27.5	31.4	21.6					32.2	22.9	23.5	18.2		
United States	28.7	25.3	27.4	28.6			30.2	31.9			30.3	28.6			29.4	27.8			36.3	34.7		

TABLE 39.—*Flaxseed: Yield per acre computed from census data of acreage and production, official estimates of the United States Department of Agriculture, and averages of yield per acre reported by crop correspondents on the county and township lists, by States, for stated years*

State	1909				1919				1924			
	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields
	Bush.	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*	*Bush.*
Minnesota	9.4	10.1	10.0	9.1	8.9	8.3	9.0	7.0	11.4	12.3	11.4	10.9
Iowa	9.6	11.0	9.8	9.1	10.9	9.9	9.5	6.3	10.2	12.5	11.7	9.9
North Dakota	9.2	9.7	9.3	9.6	4.7	5.0	5.0	4.6	7.8	8.4	8.5	7.4
South Dakota	8.5	9.5	9.4	9.2	7.9	8.0	8.0	7.0	8.8	8.8	8.9	8.3
Kansas	6.8	7.6	7.0	6.7	8.0	5.6	6.3	5.9		6.2	7.0	5.9
Montana		10.0	12.0	11.9	1.8	1.9	1.7	2.5	7.0	8.8	8.9	7.1
United States			9.4	9.4			5.3	5.3			9.2	8.2

TABLE 40.—*Cotton: Yield of lint per acre, computed from census data of acreage and production, official estimates of the United States Department of Agriculture, and averages of yield per acre reported by crop correspondents on the county and township lists, by States, for stated years*

Group of States and State	1879		1889		1899				1909				1919				1924			
	Official estimates	Census yields	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields
South Atlantic:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Virginia			83	62	180	199	120	187	104	180	190	193	200	263	255	248	154	162	180	193
North Carolina	156	183	98	127	181	168	193	204	193	211	210	235	241	243	266	287	188	168	196	224
South Carolina	143	161	141	170	148	156	165	191	146	199	210	231	210	220	240	261	153	150	160	193
Georgia	156	131	155	161	152	151	159	168	177	182	184	191	140	151	152	170	152	153	157	177
Florida	105	85	139	102	142	128	94	115	99	119	110	104	29	54	74	78	59	129	130	115
South Central:																				
Missouri					259	230	195	281	300	258	271	279	265	295	257	293	120	205	185	192
Tennessee	268	201	89	115	137	151	166	178	184	148	158	167	147	184	195	187	149	165	170	182
Alabama	170	130	163	150	131	150	176	163	136	133	142	141	120	139	122	128	155	154	154	158
Mississippi	186	201	165	184	178	193	209	210	151	147	157	159	163	166	160	155	179	180	176	174
Arkansas	275	253	217	189	159	152	193	201	141	161	153	176	157	166	155	166	115	166	169	188
Louisiana	202	257	180	240	252	176	238	246	133	148	130	131	84	88	93	108	142	136	145	165
Oklahoma									120	138	147	132	177	191	195	179	163	181	187	192
Texas	175	174	169	171	137	151	185	169	120	120	125	122	125	124	140	130	127	131	138	142
United States	188.0	172.8	158.8	168.7			183.8	180.3			154.8	156.6			161.5	163.9			157.4	166.6

TABLE 41.—*Tobacco: Yield per acre computed from census data of acreage and production, official estimates of the United States Department of Agriculture, and averages of yield per acre reported by crop correspondents on the county and township lists, by States for stated years*

Group of States and State	1879		1889		1899				1909				1919				1924			
	Official estimates	Census yields	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields	County reports	Township reports	Official estimates	Census yields
Northern:	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Massachusetts	1,500	1,599	1,580	1,389	1,755	1,621	1,850	1,674	1,500	-------	1,600	1,730	1,770	1,400	1,540	1,568	1,629	1,283	1,310	1,389
Connecticut	1,400	1,621	1,600	1,402	1,549	1,392	1,600	1,673	1,702	-------	1,650	1,752	1,427	1,689	1,560	1,567	1,550	1,315	1,315	1,335
New York	1,315	1,313	1,150	1,080	840	1,104	1,050	1,234	-------	1,048	1,175	1,301	1,350	1,303	1,290	1,284	1,800	1,178	1,175	1,136
Pennsylvania	1,459	1,340	1,280	1,074	1,089	1,169	1,100	1,495	941	881	985	1,106	1,300	1,325	1,320	1,308	1,100	1,316	1,300	1,258
Ohio	671	1,002	806	854	929	713	775	923	895	908	925	832	809	901	860	850	668	777	650	702
Indiana	840	742	608	823	846	772	700	837	1,145	955	950	903	751	944	850	835	814	881	877	890
Wisconsin	1,033	1,204	1,020	1,125	1,334	1,262	1,300	1,345	1,008	1,085	1,180	1,160	1,213	1,254	1,270	1,265	978	892	940	928
Southern:																				
Missouri	663	774	735	830	500	820	720	698	943	724	885	989	600	866	1,000	908	586	1,084	1,000	895
Maryland	633	683	400	609	647	689	810	573	677	693	710	685	719	685	675	607	847	733	765	709
Virginia	763	568	475	439	752	719	690	667	794	746	775	717	512	569	570	454	550	621	650	598
West Virginia	658	564	700	560	437	512	500	602	652	894	875	801	800	832	700	675	-------	618	800	731
North Carolina	556	472	443	375	594	577	560	628	596	611	600	626	496	613	560	610	525	544	560	583
South Carolina	-------	-------	-------	-------	750	-------	750	765	800	770	800	850	702	808	600	688	297	456	440	491
Georgia	-------	-------	-------	-------	565	-------	400	480	973	600	700	734	770	672	530	422	779	890	761	782
Florida	-------	-------	-------	-------	486	-------	490	547	779	500	710	879	-------	925	950	1,043	1,000	462	800	842
Kentucky	793	757	700	808	737	775	730	817	853	838	835	848	765	781	830	798	690	749	834	779
Tennessee	800	707	530	707	701	661	600	684	747	709	730	760	757	813	800	811	680	720	750	795
United States	795	740	645	702	-------	-------	739.2	788.0	-------	-------	804.3	815.0	-------	-------	730.8	737.0	-------	-------	733.6	719.4

TABLE 42.—*Percentage of cases in which official estimates of yield per acre, averages of yield reported by county correspondents, and averages of yields reported by township correspondents compared with yields derived from census data, by commodities, geographic groups of States,*[1] *and stated years*

Crops and group of States	Official estimates, 1879–1924				Official estimates, 1899–1924				County reports, 1899–1924				Township reports, 1899–1924			
	Within 1 bushel	Lower by 1 bushel or more	Higher by 1 bushel or more	Within 2 bushels	Within 1 bushel or more	Lower by 1 bushel or more	Higher by 1 bushel or more	Within 2 bushels	Within 1 bushel	Lower by 1 bushel or more	Higher by 1 bushel or more	Within 2 bushels	Within 1 bushel	Lower by 1 bushel or more	Higher by 1 bushel or more	Within 2 bushels
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Winter wheat:																
Northern	52	25	23	85	64	19	17	91	45	40	15	92	53	28	19	83
Southern	54	18	28	76	61	14	25	83	44	28	28	89	50	17	33	78
Northern and Southern	53	22	25	81	63	17	20	88	45	35	20	90	52	23	25	81
Spring wheat:																
Three States	93	7	0	100	92	8	0	100	42	50	8	92	83	17	0	100
Corn:																
North Atlantic	20	48	32	39	17	44	39	33	14	53	33	25	25	50	25	47
North Central	32	24	34	59	36	29	35	58	27	33	40	54	25	29	46	48
South Atlantic	31	8	61	46	28	3	69	38	31	19	50	59	12	0	88	28
South Central	37	9	54	67	34	10	56	66	34	19	47	66	38	3	59	53
Far Western	20	6	74	26	15	5	80	26	18	13	69	31	8	5	87	15
United States	28	23	49	48	26	19	55	44	25	28	47	46	21	19	60	39
Oats:																
North Atlantic	22	32	46	43	19	25	56	31	11	31	58	28	17	28	55	28
North Central	19	25	56	56	25	15	60	62	37	23	40	58	29	19	52	58
South Atlantic	15	10	75	38	13	9	78	28	9	19	72	31	9	3	88	25
South Central	15	7	78	29	13	3	84	23	10	3	87	16	3	3	94	13
Far Western	18	16	66	29	15	12	73	22	15	24	61	22	10	12	78	19
United States	18	19	63	41	18	13	69	35	18	21	61	33	15	14	71	31
	Within 0.5 bushel	Lower by 0.5 bushel or more	Higher by 0.5 bushel or more	Within 1 bushel	Within 0.5 bushel	Lower by 0.5 bushel or more	Higher by 0.5 bushel or more	Within 1 bushel	Within 0.5 bushel	Lower by 0.5 bushel or more	Higher by 0.5 bushel or more	Within 1 bushel	Within 0.5 bushel	Lower by 0.5 bushel or more	Higher by 0.5 bushel or more	Within 1 bushel
Flaxseed:[3] 3 States					39	6	55	67	63	12	25	81	33	11	56	67

	Within 10 pounds	Lower by 10 pounds or more	Higher by 10 pounds or more	Within 20 pounds	Within 10 pounds	Lower by 10 pounds or more	Higher by 10 pounds or more	Within 20 pounds	Within 10 pounds	Lower by 10 pounds or more	Higher by 10 pounds or more	Within 20 pounds	Within 10 pounds	Lower by 10 pounds or more	Higher by 10 pounds or more	Within 20 pounds
Cotton:																
South Atlantic	34	59	17	48	30	65	5	55	10	85	5	20	5	70	25	35
South Central	42	32	26	77	52	29	19	93	39	55	6	45	29	55	16	77
United States	36	43	21	65	45	43	12	78	27	67	6	33	20	61	19	61
	Within 50 pounds	Lower by 50 pounds or more	Higher by 50 pounds or more	Within 100 pounds	Within 50 pounds	Lower by 50 pounds or more	Higher by 50 pounds or more	Within 100 pounds	Within 50 pounds	Lower by 50 pounds or more	Higher by 50 pounds or more	Within 100 pounds	Within 50 pounds	Lower by 50 pounds or more	Higher by 50 pounds or more	Within 100 pounds
Tobacco:																
Northern	40	41	19	57	54	39	7	68	30	40	30	52	27	46	27	62
Southern	39	30	31	74	45	27	28	82	34	37	29	60	40	30	30	62
Northern and Southern	40	34	26	67	49	32	19	76	32	39	29	57	35	36	29	62

[1] The number of cases (States by years) in each category is expressed as a percentage of all cases included in the comparison.
[2] States in the groups designated are shown in Tables 36–41.
[3] 1909–1924.

TABLE 43.—*Percentage of cases in which official estimates of yield per acre, averages of yields, reported by county correspondents, and averages of yields reported by township correspondents compared with yields derived from census data, by commodities and stated years* [1]

Crop and year	Official estimates				County reports				Township reports			
	Within 1 bushel	Lower by 1 bushel or more	Higher by 1 bushel or more	Within 2 bushels	Within 1 bushel	Lower by 1 bushel or more	Higher by 1 bushel or more	Within 2 bushels	Within 1 bushel	Lower by 1 bushel or more	Higher by 1 bushel or more	Within 2 bushels
Winter wheat:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1879	30	0	70	65								
1889	35	65	0	70								
1899	60	35	5	85	40	60	0	90	65	30	5	90
1909	57	14	29	95	43	24	33	66	33	19	48	66
1919	71	0	29	90	52	19	29	90	53	14	33	81
1924	62	19	19	81	43	38	19	76	57	29	14	86
Corn:												
1879	30	14	56	53								
1889	36	49	15	59								
1899	38	42	20	58	31	42	27	55	29	31	40	60
1909	24	21	55	34	21	32	47	36	21	19	60	30
1919	13	2	85	34	26	19	55	47	13	13	74	23
1924	31	13	56	52	21	19	60	48	23	12	65	42
Oats:												
1879	11	17	72	25								
1889	26	44	30	79								
1899	22	36	42	51	22	33	45	42	29	22	49	47
1909	15	8	77	33	21	23	56	29	8	19	73	27
1919	11	6	83	21	11	11	78	26	15	8	77	28
1924	23	4	73	35	19	17	64	35	8	6	86	23
	Within 0.5 bushel	Lower by 0.5 bushel	Higher by 0.5 bushel	Within 1 bushel	Within 0.5 bushel	Lower by 0.5 bushel	Higher by 0.5 bushel	Within 1 bushel	Within 0.5 bushel	Lower by 0.5 bushel	Higher by 0.5 bushel	Within 1 bushel
Flaxseed:												
1909	67	0	33	100	80	20	0	100	33	17	50	67
1919	33	17	50	67	17	17	66	50	33	17	50	83
1924	17	0	83	33	100	0	0	100	33	0	67	50

	Within 50 pounds	Lower by 50 pounds	Higher by 50 pounds	Within 100 pounds	Within 50 pounds	Lower by 50 pounds	Higher by 50 pounds	Within 100 pounds	Within 50 pounds	Lower by 50 pounds	Higher by 50 pounds	Within 100 pounds
Tobacco:												
1879	21	36	43	57								
1889	14	43	43	29								
1899	23	65	12	59	35	41	24	71	14	64	22	57
1909	47	35	18	65	44	31	25	56	27	53	20	67
1919	65	12	23	88	25	37	38	56	41	12	47	53
1924	59	18	23	94	25	44	31	44	53	24	23	71
	Within 10 pounds	Lower by 10 pounds or more	Higher by 10 pounds or more	Within 20 pounds	Within 10 pounds	Lower by 10 pounds or more	Higher by 10 pounds or more	Within 20 pounds	Within 10 pounds	Lower by 10 pounds or more	Higher by 10 pounds or more	Within 20 pounds
Cotton (lint):												
1879	10	40	50	30								
1889	18	46	36	36								
1899	33	42	25	67	17	75	8	25	0	83	17	50
1909	69	23	8	77	39	46	15	46	31	54	15	69
1919	46	46	8	77	39	61	0	39	31	38	31	69
1924	31	61	8	85	15	85	0	23	15	70	15	54

[1] The number of cases (States by years) in each category is expressed as a percentage of all cases included in the comparison. Figures are for States in groups shown in Tables 36–41.

TABLE 44.—*Coefficients of correlation between yields derived from census data and official estimates of the United States Department of Agriculture, averages of yields per acre reported by county correspondents, averages of yields reported by township correspondents, for stated years*

Crop and group of States[1]	Census yields and official estimates					Census yields and averages of county reports					Census yields and averages of township reports					County and township reports				
	1899	1909	1919	1924	4 years	1899	1909	1919	1924	4 years	1899	1909	1919	1924	4 years	1899	1909	1919	1924	4 years
Winter wheat:																				
Northern	0.954	0.967	0.929	0.883	0.945	0.973	0.939	0.883	0.791	0.919	0.973	0.931	0.893	0.836	0.900	0.994	0.952	0.949	0.858	0.958
Southern	.980	.950	.793	.947	.907	.939	.943	.864	.927	.878	.973	.566	.869	.894	.856	.915	.637	.958	.830	.878
Northern and Southern	.960	.966	.943	.818	.947	.931	.951	.926	.920	.929	.955	.889	.940	.925	.918	.956	.938	.977	.901	.955
Spring wheat:																				
Three States	------	------	------	------	.989	------	------	------	------	.958	------	------	------	------	.996	------	------	------	------	.976
Corn:																				
North Atlantic	.831	.710	.744	.873	.722	.610	.502	.636	.141	.532	.497	.435	.482	.625	.550	.263	.882	.724	.162	.668
North Central	.910	.913	.902	.913	.884	.811	.855	.853	.931	.848	.948	.891	.929	.930	.915	.872	.976	.934	.880	.937
South Atlantic and South Central	.905	.969	.969	.985	.930	.951	.882	.955	.950	.992	.986	.953	.844	.982	.978	.935	.803	.840	.927	.869
Far Western	.897	.455	.853	.872	.755	.340	.478	.622	.691	.600	.900	.782	.792	.830	.788	.310	.612	.310	.646	.507
United States	.964	.855	.956	.954	.915	.932	.803	.867	.982	.850	.966	.865	.875	.934	.891	.894	.899	.800	.845	.852
Oats:																				
North Atlantic	.853	.798	.835	.563	.691	.681	.395	.814	.175	.427	.854	.330	.832	.180	.572	.899	.971	.848	.755	.800
North Central	.950	.948	.975	.978	.944	.933	.875	.965	.972	.949	.960	.914	.946	.977	.942	.965	.906	.977	.948	.943
South Atlantic and South Central	.856	.903	.923	.966	.879	.727	.790	.918	.880	.830	.881	.774	.932	.960	.904	.808	.878	.899	.878	.876
Far Western	.897	.791	.830	.804	.805	.817	.446	.403	.221	.470	.895	.816	.360	.704	.805	.853	.801	.682	.577	.718
United States	.961	.899	.891	.927	.906	.929	.811	.742	.672	.795	.950	.872	.892	.875	.892	.947	.954	.803	.826	.890
Flaxseed:																				
Six States	------	.964	.944	.964	.928	------	.862	.894	.993	.822	------	.621	.897	.958	.883	------	.914	.953	.932	.914
Cotton:																				
Southern	.726	.981	.734	.911	.929	.877	.778	.955	.715	.875	.825	.977	.958	.665	.906	.786	.800	.966	.374	.818
Tobacco:																				
Northern	.917	.978	.999	.985	.942	.810	.876	.955	.804	.799	.946	.929	.948	.972	.916	.892	.965	.820	.785	.823
Southern	.655	.740	.917	.936	.848	.595	.574	.472	.689	.603	.749	.168	.871	.632	.576	.680	.089	.696	.127	.307
United States	.941	.972	.986	.980	.962	.928	.911	.914	.884	.885	.961	.913	.962	.909	.918	.936	.889	.914	.756	.858

[1] States in the groups designated are shown in Tables 36–41.

In approaching the problem of a relative comparison of the different indications of yield per acre, simple correlation coefficients between the two series of yield per acre are calculated by States, for a given geographic division for each census year. Additional correlation coefficients are calculated for all the years combined for a geographic division; also other correlation coefficients for all States for any one year; and, finally, a single correlation coefficient for each crop in which all States for all years are included. These correlation coefficients appear in Table 44.

A comparison between the yields as reported by the county correspondents and the yields as reported by the township list was also made by means of simple correlation coefficients shown in Table 44.

These correlation coefficients are not corrected for the influence of the size of sample, which is small for any one group of States in a single year, and some allowance should be made for this when interpreting the results of their comparison.

WHEAT

For comparative purposes the States that are almost entirely winter-wheat States are divided into two groups (1) Northern and Great Plains States and (2) Southern States, whereas the States that have grown both spring and winter wheat, such as Iowa, Wisconsin, Montana, and the far Western States, are excluded from the comparison because of the possibility of confusion on the part of the farmer in reporting the two kinds of wheat separately either to the census enumerator or as a crop reporter. Separate comparisons are made for the three most important and almost exclusively spring-wheat States of North Dakota, South Dakota, and Minnesota. (See Table 36 for the States included in these three different groups.) The yield per acre of winter wheat as reported by crop reporters and as officially estimated by the department in the winter-wheat States is compared with the yield per acre of all wheat as reported by the census in these States, and spring wheat in the three spring-wheat States is compared with all wheat from the census.

Official estimates of yield per acre of winter wheat check more closely with yields derived from census data during the last four census years than when the two early census years, 1879 and 1889, are included in the comparison. The official estimates of the yields of winter wheat check within 1 bushel with the yields as derived from census data in 53 per cent of the cases, and within 2 bushels in 81 per cent of the cases, when all six census years are included in the comparison; but when the comparison is limited to the last four census years, these two indications check within 1 bushel in 63 per cent and within 2 bushels in 88 per cent of the cases. (Table 42.) In 1879 the estimates were based primarily on yield data as reported by county crop correspondents and weighted by county weights. By 1889 the reports from the part-time State agents supplemented the reports from the list of county reporters. By 1899 reports from the township list of reporters, unweighted, were included as an additional basis for the official estimates.

The yields from official estimates and from census check a little more closely on the basis of direct comparison in the Northern States than in the Southern States during the last four census years. This slight difference in favor of the Northern States becomes even more

significant when the higher average yields per acre in the Northern States are taken into consideration, for a check within 1 bushel is a closer check when yields generally are above 12 bushels per acre, as in the Northern States, than when yields are generally below 12 bushels per acre, as in the Southern States.

The official estimates of yields check more closely with the yields derived from the census than do the reports from the samples of county or township correspondents. (Table 42.) The sample data check just about as closely with the census data in the Southern States as in the Northern States. There is not a great deal of difference, however, between the yields as reported by the county correspondents and the yields reported by the township correspondents in percentage of cases which check within 1 or 2 bushels of the yields derived from the census. A larger percentage of the yields from the township reporters check within 1 bushel, whereas a larger percentage from the county list check within 2 bushels.

In the three spring-wheat States the several inaications of yield per acre check much more closely on an absolute basis than in the winter-wheat States. In over 90 per cent of the cases the official estimates of yield and the yields derived from the census check within 1 bushel, and in all cases they check within 2 bushels. The yields as reported by the township list check more closely with the census than do those from the county reporters.

The several indications check more closely with yields of spring wheat than with winter wheat, in part because the comparison is limited to the three most important spring-wheat producing States, where the crop is grown in large fields and where the acreage as reported by the farmers to the census enumerator corresponds closely with the acreage from which the reported production is harvested.

In the Northern States, which include the important commercal producing areas of winter wheat in the Great Plains region, therei is only a very slight tendency for the official estimates to be less than the yields as shown by the census. This slight tendency is apparent for the six census years combined as well as for the four more recent census years. (Table 42.)

Although both the official estimates of spring-wheat yield and the yields obtained from sample data check closely with the yields as derived from the census (Table 42), the general tendency is for both the official estimates and the sample data to be higher than the yields as derived from the census. This is probably due to the fact that crop correspondents in the spring-wheat States tend to exclude the yields of durum wheat from their estimate of spring-wheat yields.

From the Southern States the yields reported by the township correspondents as well as the official estimates tend to be above the yields as derived from census data in a greater number of cases than in the Northern States. This is probably accounted for by the fact that in the Southern States wheat fields are smaller and more irregular in shape than in the States of the North and of the Great Plains, while harvesting methods and utilization of the crop are less uniform.

The yields derived from the census and the official estimates check much more closely during each of the last four census years than during 1879 and 1889. It is also interesting that in 1879, 1909, and 1919 there is a marked tendency for the official estimates to be higher than the yields derived from the census, whereas, in

1889 and 1899, the tendency is in the opposite direction and, in 1924, there is no marked tendency in either direction. In general, the yields from the township list check more closely with the yields from the census than do the yields from the county reporters. The sample indications of yields tend to be lower than the yields from the census years 1899 and 1924 and higher in 1909 and 1919; the two indications of yield from sample data are consistent in this tendency to be above the census yields in certain years and below them in other years. It is especially interesting that only in 1924 did the official estimates fail to reflect the bias that apparently was shown by the two indications from the sample data.

In Minnesota, North Dakota, and South Dakota the official estimates of yield per acre of spring wheat and the yield as derived from the census check within 1 bushel in 14 of 15 cases compared. (Table 36.) The county samples and the census yields check within 1 bushel in 5 out of 12 cases, and the township sample checks within 1 bushel in 10 of the 12 available comparisons.

Official estimates of wheat yields and yields as derived from the census check within 1 bushel in 5 of the 6 census years in West Virginia and Kentucky; in 4 of the 6 census years in Kansas, Illinois, Indiana, Pennsylvania, New Jersey, Virginia, and Tennessee; in 3 out of 6 years in New York, Missouri, Maryland, and North Carolina; while the two indications have checked within 1 bushel in all three census years since Oklahoma became a State. Although in Ohio they check within a bushel in only 2 of the 6 years, they check within 2 bushels in all 6 years. In all 6 years these two indications also check within 2 bushels in Missouri, Nebraska, Kansas, and Tennessee.

The fact that the yields as derived from the census and the official estimates check as closely as they do in the Northern and Great Plains States and in the important spring-wheat States, as well as in the South, justifies the conclusion that on an average both are fairly close to the true yield per acre.

In any one year or, in any one State factors may be tending to make one figure higher or lower than the other, and these must be determined and allowed for, so far as is possible, in making an estimate of yield per acre. In making estimates from samples obtained from crop correspondents it is necessary to allow for the slight bias toward understatement on the part of the correspondents in these important wheat-producing States. In the less important wheat-producing States of the South, yields as reported by crop correspondents probably are closer to the actual yield than are those derived from the census data.

As might be expected, when the several indications are compared on the basis of the correlation between any two series, as shown in Table 44, it is again apparent that the yields from census data check more closely with the official estimates for spring wheat in the three important spring-wheat States, than with those for winter wheat even in the Northern States. The correlation coefficient between yields as derived from the census and the official estimates of yield for spring wheat is +0.989 in the last four census years and +0.996 for all six of the census years, indicating about 98 to 99 per cent of covariation between the two series of data (coefficient of determination or the percentage of covariation is taken as equal to the square

of the correlation coefficient). With winter wheat the correlation is +0.949 or about 90 per cent of covariation between yields derived from the census and official estimates of yield per acre.

On the basis of correlation, which shows the extent to which the variations in yields from State to State and from year to year for one indication are associated with variations in the other indication, it is evident (Table 44) that official estimates of yields as reported by county correspondents and yields as reported by township reporters all check more closely with the census in the Northern States than in the Southern States. It is rather surprising to find, that although the township sample of yields checks more closely with the census than does the county sample when considered on an absolute basis of the proportion of the total number of cases in which each checked within 1 or 2 bushels of the census yields, when considered on the basis of correlation the county sample shows a slightly higher degree of correlation with the yields as derived from the census than does the township sample, in both the Northern and the Southern States.

Although in general, the correlation is higher between official estimates and yields as derived from the census, there is one year, 1924, when both sample indications are more highly correlated with the census data than are the official estimates.

From Table 44 it can be seen that the correlation between the yields obtained from county reporters and those from township correspondents is higher than those between the yields from either of the two sample indications and the yields from the census, and even slightly higher than the correlation between the official estimates and the yields derived from the census.

In 1909 in the Southern States the correlation coefficient between county and township yields is only +0.637, and +0.566 as between township and census yields. Further analysis by means of scatter diagrams reveals the fact that the yield as reported by the township list for South Carolina was the observation which is at fault, and that except for this one observation, the correlation was fully as high for that year as for any of the other years.

CORN

In the North Central States, where more than two-thirds of the corn crop is produced, the official estimates check within 1 bushel with the yields as derived from the census in about one-third of the cases; the official estimates are below the census yields in about one-third of the cases and are above in one-third (Table 42). With corn yields the checking of two separate indications within 1 bushel is nearly as significant as having wheat yields check within 0.5 bushel, because corn yields are frequently twice as large as wheat yields. When this is taken into consideration, it may be said that in the important corn-producing States, corn yields derived from the census and those officially estimated check as closely as do wheat yields in important wheat-producing States.

There is a tendency in the case of corn for both the sample data and the official estimates of yield to be higher than yields derived from census data. This tendency is probably due to the fact that an appreciable proportion of the corn acreage is not harvested for grain, but is used otherwise. Consequently, when the production of corn as reported to the census enumerator is divided by an acreage

somewhat larger than that on which the harvested production is grown, the resulting yield per acre is too low. This situation is even more pronounced in the South, where the corn crop is interplanted and there are both early and late crops.

In the far Western States the official estimates and the yields as reported by the crop correspondents are usually much higher than the census yields. Probably this is partly because the sample data are not quite representative, as it is extremely difficult to obtain an adequate sample from the lower-yielding dry-land areas, and from the less successful irrigation projects.

In the North Atlantic States the official estimates and the yields as reported by the crop reporters tend to be lower than the yields derived from the census. This may be caused by the regional tendency on the part of farmers to report the yield of corn in bushel baskets of ears rather than in standard bushels as specified in the yield questionnaires of the department. Although this designation is not observed by all crop reporters, there are probably fewer errors of this sort in the returns from crop reporters than in the returns to census enumerators.

Official estimates of corn yields and the yields derived from the census check within 1 bushel in five of six years in Kansas, where the State average yield has varied from as low as about 16 bushels in 1919 to as high as 28 bushels in 1899. In Kansas the corn crop matures early, and farmers know by the first of November just about what the yield is likely to be when harvest is completed. As relatively little corn is used for silage, soilage, or hogging down in Kansas and as frost damage to corn occurs less frequently than in many other States, these two indications may be expected to check more closely in Kansas than in many of the other important corn-producing States.

Official estimates of corn yield and yields derived from the census check within 1 bushel in 4 of the 6 years in Missouri and New York, where corn yields are high, in Florida, Tennessee, and Alabama, where corn yields are low, and also in Oregon, a State in which only a small acreage of corn is grown. These two indications of corn yield check within 1 bushel in 3 of 6 years in Wisconsin, Missouri, Nebraska, South Carolina, and Georgia. They check within 2 bushels in 5 of 6 years in New York, Minnesota, Kansas, Mississippi, and Tennessee, and in 4 of 6 years in Pennsylvania, Ohio, Wisconsin, Missouri, Georgia, Florida, Arkansas, Louisiana, and Oregon.

It is interesting that, as shown in Tables 42 and 43, the yields from the county list check about as closely with yields derived from the census, as do the township samples, although the correlations in Table 44 are somewhat higher for the township and census yields than for the county and census yields. The correlations are generally lower with the various indications of corn yields than with the indications of wheat yields, and even the county and township reports shown in Table 44 show a positive correlation of only 0.852 for samples of corn yields, as compared with 0.955 for the samples of wheat yields.

The difficulty with the sample data on yields of corn that was due to the date on which the inquiry was previously made has been mentioned.

OATS

Official estimates as well as the sample indication of oat yields check much more closely with yields as derived from the census data in the North Central States, where the bulk of the crop is produced, than in other parts of the country. (Table 42.) In all sections of the country and in all the census years there is a pronounced tendency for official estimates of oat yields and the indications of yield from sample data to be higher than yields derived from the census. This tendency is somewhat less in evidence in the North Central States, than elsewhere. Again it is undoubtedly the old difficulty of the farmers reporting a larger acreage to the census enumerator than was actually harvested and threshed as grain. Since oats are primarily a feed crop and farmers utilize them on the farm in the most economical manner, the smaller the acreage per farm the less likely is the farmer to harvest and actually thresh his oats.

In spite of the marked tendency for the official estimates of oat yields to be higher than the yields shown by the census, these two indications check within 2 bushels in all of the 6 of the census years in Ohio and Illinois; in 5 of 6 years in Maine and Michigan; in 4 of the 6 years in New York, Indiana, and Minnesota; in 2 of the 6 years in Connecticut, Pennsylvania, North Dakota, Delaware, Maryland, South Carolina, Florida, Alabama, Mississippi, and Colorado; and within 2 bushels in 2 of the 4 census years for which estimates for South Dakota are available.

Although the oat yields indicated by the sample data are generally higher than those shown by the census, the correlations (Table 44) between census yields and township yields are fully as high, +0.89, as for corn yields. In the North Central States the correlations between sample data yields and census data are higher with oats than with either corn or wheat. The correlations between county and township indications of yield (Table 44) are higher for oats, +0.89, than for corn, +0.85, but not so high as for wheat. The correlation for wheat might be expected to be higher, since the far Western States are omitted from the comparison for wheat, whereas they are included in those for oats and corn.

FLAXSEED

Official estimates of flaxseed acreage, yield per acre, and production were not made until 1902, and consequently only three census years are available for this comparison of crop-yield indications. Since the average yield per acre of flaxseed for a State seldom exceeds 12 bushels, the absolute comparisons of the several indications of yield per acre are placed on the basis of checking within 0.5 and 1 bushel instead of 1 and 2 bushels as with the other grain crops. There are at present only four States—North Dakota, South Dakota, Minnesota, and Montana—where the growing of flaxseed is at all important. It is of very minor importance in the other two States, Iowa and Kansas, included in this study. Wisconsin, Missouri and Nebraska have produced a little flax during the period covered by this study, but in these States the crop is of such minor importance and the acreage so small that it is practically impossible to obtain reports on it from the crop correspondents.

Official estimates of flax yields check less closely with the yields indicated by census data, in successive census years. (Table 43.) The

number of States in which these two indications check within 0.5 bushel is 67 per cent of the total number of States growing flax in 1909, 33 per cent in 1919, and only 17 per cent in 1924. The percentage of States checking within 1 bushel declines from 100 per cent in 1909 to 67 per cent in 1919, and to only 33 per cent in 1924. No such trend is apparent in the yields obtained from county or township reporters.

In practically all instances where the official estimates or sample indications fail to check with the census yields within 0.5 bushel, they are higher than the census yields. This would seem to indicate that either there is a plus bias in the reports of the crop correspondents and perhaps in the official estimates as well, or that the sample is not fully representative of the lower-yielding areas of flax production. Flax is considered primarily a new-land crop, and wilt-resistant varieties that permit its production on land that has been under cultivation for some time have been developed only in recent years. This may account in part for the decreasing tendency of the official estimates and census yields to check in successive census years.

Introduction of wilt-resistant varieties has tended to increase the yield per acre in the older farming sections of the States from which the bulk of the crop reports are received, while at the same time the acreage of flax has also expanded westward into less humid areas, especially in North Dakota and South Dakota. There is always some lag in the adjustment of acreage weights where the acreage of a crop is expanding and there is also difficulty in obtaining regular crop correspondents in new farming sections. As a result, the lower-yielding sections of expanding flax acreage would not be fully represented, either in the reports of yield or in the system of weights used; the weighted averages of 1919 and 1924 would tend therefore to be too high and might be expected to be higher than the yields calculated from census data. Census indications of yield per acre should be highly reliable with the flax crop because it is not fed or used on the farm in any way except for seeding purposes.

In these six States the yield as reported by the county reporters check much more closely with yields as derived from the census (Table 42) when considered on an absolute basis than do the official estimates or the reports from the township list. In 1909, the yields derived from the census data and those obtained from the county reporters check within 0.5 bushel in 80 per cent of the States for which county data are now available, while the two indications check within 1 bushel in all five States. In 1924 they check within 0.5 bushel in the five States for which a report from the county list is now available, whereas in 1919 they check within 0.5 bushel in only one State, and within 1 bushel in only one-half the number of States. In North Dakota and South Dakota the yields as reported by the county list as well as those from the township list check within 1 bushel with the yields derived from the census data in all three census years.

However, the correlation between official estimates and yields derived from the census is somewhat higher than the correlations between census yields and either of the sample indications. (Table 44.) Although the correlation between official estimates and census yields is higher than that between yields reported by the two lists of crop correspondents, the correlation between the latter is higher than that between yields derived from census data and either of the sample indications. The census yields and those reported by the county reporters however, show a correlation of $+0.993$ in one year, 1924.

This comparison of yield data for flaxseed shows (1) that the several indications of yield per acre check about as closely with this crop as could be expected for any crop and (2) that in making estimates of the yield per acre of flaxseed the statistician must be on his guard against a sample that is not fully representative of the lower-yielding sections of these States.

COTTON

Comparing official estimates of yields per acre of cotton and sample data yields with those obtained from census data probably is less satisfactory than making similar comparisons for any other crop. Each year since 1902 the Census Bureau, through special agents, has obtained the data on cotton ginning direct from the cotton gins. As might be expected serious difficulties have been encountered in making a farm-to-farm enumeration that will check exactly with ginning figures of cotton production. Consequently such adjustments must be made in tabulating and summarizing the data that a reliable indication of yield per acre is not likely to be obtained by dividing the production by the acreage.

The production of cotton as reported by the census is not necessarily from the acreage as reported by the census. In 1900 difficulty and confusion arose from the fact that production was reported both in bales and pounds of lint. In 1909, the first census after ginning reports had become well established, more cotton was enumerated than was reported as ginned, because of a duplication of reports on the production of cotton, when the same field of cotton was in some instances reported to the enumerator twice, once by the landlord and again by the tenant. This difficulty arose largely from the construction of the schedule on which data from cropper tenants and data for the whole plantation became difficult to separate and distinguish.

With the funds available it became necessary in many of the States to base the yields per acre largely on the estimates of the Department of Agriculture, and the acreage of cotton became a derived figure, obtained by dividing the total production ginned by these estimates of yield per acre. In this analysis cotton yields from census data in 1909 appear to check more closely with the official estimates than for any other census year. In 1909, yields per acre derived from the census and official estimates of yield, check within 10 pounds in about 69 per cent of the States, and in other years such a close check as 10 pounds occurs in less than one-third of the States, except in 1919 when they checked within 10 pounds in 46 per cent of the States. (Table 43.) The correlation between these two indications (Table 44) is very high that year, +0.98, in comparison with about +0.73 in 1899 and in 1919, and +0.91 in 1924.

In 1924 the census enumeration showed less cotton that had been accounted for by the ginning reports, and consequently adjustments were made which tended to impair the reliability of the yield-per-acre figure derived by dividing total production by the acreage enumerated. The census of 1919 is apparently the most satisfactory of the last three census years when cotton ginnings have been available to the Census Bureau as a check on the accuracy of the enumeration of cotton acreage and production. In 1919 the correlation between the census yields and the yields from the county sample and between census yields and yields from the township sample were both +0.95, as compared with those in 1924, when the county-census correlation was +0.71 and

the township-census correlation was +0.66. The county-township yields showed a correlation of +0.97 in 1919, the highest for any of the four census years. (Table 44.)

The further difficulty encountered in comparing cotton yields is that the unit of measure for the census is the bale, or fraction thereof, whereas pounds of lint cotton are used for the official estimates and yield questionnaries of the Department of Agriculture. The bales per acre shown by the census were converted to pounds of lint on the basis of bale weights, by States, as published by the census, with allowance of 22 pounds for tare on each bale. Definite data on bale weights were not available by States for 1879 and 1889, and consequently it was necessary to interpolate for the separate States on the basis of the usual deviations of the weight per bale for each State as compared with the average for the United States.

Although because of the limitations of the data only very broad generalizations concerning cotton are justified, it is evident, from Tables 42 and 43 that the official estimates of the yield per acre as well as the yields reported by the crop correspondents, check with the yields derived from the census more closely in the South Central States than in the Atlantic Coast States. The indications derived from census data are consistently higher than those from sample data, indicating considerable bias on the part of crop reporters' estimates, a bias apparently more pronounced in the Atlantic Coast States than in the States farther west. With the greater amount of bias it is not surprising to find that the official estimates are apparently on a lower level relative to the census indications of yield in the South Atlantic States than in the South Central States.

The tendency toward a downward bias on the part of the sample data and the official estimates apparently has become much more pronounced since the beginning of reports of the ginnings of cotton during the decade from 1899 to 1909, although it is also apparent that the official estimates and the yields derived from the census check more closely during the last three or four census years than during the first two, 1879 and 1889. In Texas the official estimates of yield and the yield derived from the census check within 10 pounds in 5 of the 6 census years and within 20 pounds in all of them. In Mississippi the two indications check within 10 pounds in the last 4 census years and within 20 pounds in 1879 and 1889. In Alabama they check within 10 pounds in 3 years, and within 20 pounds in all of the last 5 census years.

Among the Atlantic Coast States Georgia has the best record with three census years, 1889, 1899, and 1909, when the official estimates and the census yields check within 10 pounds, but the official estimates are below the census yields in 1919 and 1924. In both of the Carolinas the official estimates are below the census yields in all six of the census years, and in only one year in each State do the indications check within 20 pounds.

In making official estimates of cotton, empnasis has always been placed on making an estimate of production that would check closely with the ginning figures of production; prior to the ginning reports elaborate data were gathered on shipments by railroad and by boat from each cotton State, to serve as a final check on the production estimates. The current estimates of production are based in part on an interpretation of the current ginning reports made public twice a

month during the season of harvest. The later in the season the forecast of production is made, the greater is the dependence placed on the ginnings up to that date as an indication of final production. By the first of December, when the preliminary estimates of yield per acre are made, that indication of production which consists of the acreage of cotton multiplied by yield per acre, is not considered very significant in comparison with the indication of production derived from an interpretation of ginning data.

The low correlation of +0.726 in 1899 (Table 44) between official estimates of yield and yields derived from the census can be attributed primarily to the low official estimates in Missouri and Virginia, both States of minor importance in cotton production, where the official estimates are much lower than the indications from the township and county samples as well as lower than the census. The same situation occurred again in Missouri in 1919.

The low correlation +0.715 in 1924 between yields derived from census data and yields from county reporters is due largely to low yields reported by the county sample in Missouri and Arkansas. These same low reports explain the low correlation between the county and township indications for that year.

TOBACCO

In about one-half of the States in the census years 1899, 1909, 1919, 1924, the yields of tobacco derived from the census data check within 50 pounds with the official estimates of yield; in three-fourths of the States these two indications check within 100 pounds. (Table 42.)

These two indications check within 50 pounds and 100 pounds about as frequently in the Northern States as in the Southern States, although yields per acre tend to run somewhat higher in the North. In 1919 the official estimates and the census yields checked within 50 pounds in all of the seven important Northern States growing tobacco, showing a correlation coefficient of +0.999. (Table 44.) These two indications apparently show (Table 43) an increasing tendency to check in successive census years, due in part to the increasing importance of tobacco as a farm crop, to the development of better methods of handling sample data, and to more effective use of information concerning the quantity of this crop sold. The larger the acreage and the more important a crop becomes in a State, the more accurate and reliable will be both the census enumerations and the sample data concerning yields per acre. In the earlier census years, 1879 and 1889, the official estimates of the yields of tobacco and the yields derived from the census check within 50 pounds in only a few States—New York, Maryland, and Kentucky in 1879, and Ohio and Virginia in 1889. On the other hand, in five States, Kentucky, Tennessee, North Carolina, Indiana, and Wisconsin, these indications check within 50 pounds in each of the last three census years.

In 1899 and 1909 the yield samples from the county correspondents check more closely with the census on the basis of a direct comparison (Table 43), whereas in 1919 and 1924 the yield samples obtained from the township list check more closely. It will be recalled that the reports from the county list, although small in number in comparison with the township list, were weighted by counties. The township samples were not weighted in 1899 or 1909, so far as can be

determined now, but by 1919 the more important crops were being weighted by crop-reporting districts. With the development of a strong list of field correspondents and the appointment of full-time field statisticians in practically all States in the decade from 1910 to 1920, it is reasonable to expect that the list of county correspondents was not so well maintained nor were new recruits added so promptly when old reporters dropped out. This apparent tendency is not in evidence with crops such as corn, oats, wheat, and cotton, which are produced more generally. The problem of obtaining a representative sample is usually much more difficult with a crop of localized production, like tobacco, than with the more generally grown crops, and it is possible that a small sample properly weighted would be more accurate than a large sample not weighted.

In 1899 the official estimates did not check as closely with the yields derived from census data as did the sample data from the county reporters; by 1909 the estimates checked about as well as the county sample; and in 1919 and 1924 the estimates checked much more closely with the census on an absolute basis than the township sample. Information concerning the sales of tobacco was probably given greater consideration than in the earlier years.

In the Southern States the cases are equally divided into two categories (1) those in which the official estimates are lower than the yields as derived from the census, and (2) those in which the official estimates are higher. This situation also exists when the data for the six census years are combined for comparison, as well as for the last four census years, and for each individual year of the last four census years. The deviations of the yields reported by the township from the census yields also show an equal division for the four years combined although in individual years there is considerable variation. The apparent absence of any material bias in reporting yields of tobacco may be due to the early maturity of the crop and early sales. The crop is entirely marketed in several of the Southern States before the yield inquiry is made in the fall. Consequently, farmers are well informed concerning their own yields and, with the crop rather well out of their hands, there is little incentive to understate the yield per acre when reporting to the department.

In the Northern States there is a tendency for both the official estimates and the sample data to be higher than the yields derived from the census data thereby indicating bias in the individual observations. The bias is more in evidence with the township sample of yields than with the county sample.

Official estimates of tobacco and yields as derived from the census show a higher correlation than do winter wheat, oats, corn, or cotton, although the correlations between sample data of yield and the census yield are about the same as with the other crops. (Table 44.) The correlation between the county samples and the township reports is lower for tobacco than for oats, winter wheat, spring wheat, or flax, but higher than for cotton, and about equal to that for corn.

Although the yields as derived from the census and the official estimates of yield tend to check with greater absolute accuracy with the passage of time, the correlation coefficients between county and township reports shows no tendency to become larger in the later census years. The official estimates of yield are more highly correlated with yields derived from the census, +0.962, than is the case

of the county sample, +0.885, or the township sample, +0.918. Although the official estimates and sample data show less indication of bias in the Southern States than in the Northern States, less correlation is shown in the North between official estimates and census yields, and between county data and census yields, and for yields obtained from the township correspondents and the yields derived from the census. The two sample indications of yield of tobacco (Table 44) show very low correlations in the Southern States, whereas in the North there is a substantial correlation between them. In fact, with the six crops considered in this analysis, it is only in the case of tobacco in the South that the county samples and township samples show really low correlation. This would indicate that these samples are small and, having considerable dispersion, are consequently subject to high probable errors and are not likely fully to represent the important tobacco-producing areas.

In several of the Southern States in which the tobacco acreage is small and highly localized, it is difficult to obtain an adequate sample that is fully representative. Fortunately other samples as well as check data from sales are available as a basis for estimates of production.

GENERAL CONSIDERATIONS IN REGARD TO COMPARISONS OF YIELD ESTIMATES

Official estimates of yields per acre check sufficiently well with the yields derived from census data, when allowance is made for the inherent limitations of such data, to justify the conclusion that, for important crops in all but the smallest States and the far Western States, these two entirely separate indications of yield undoubtedly approximate closely the true yield per acre. The differences between them for a given crop are seldom more than might be expected from the application of the principles of sampling as made earlier in this study. Bias is likely to be present in the reported yields of important cash crops, especially when such crops are practically the only source of farm income, as with cotton. A small sample is to be trusted only within rather wide limits, and lack of representativeness is a constant source of error in the sample data of yield per acre, as in the case of tobacco in States of small tobacco acreage. These difficulties have apparently been recognized by the Crop Reporting Board for many years, for with most crops the official estimates check more closely with yields as derived from census data than do either of the direct sample indications; and with all the crops studied, the correlation between census yields and official estimates, is higher than that between census yields and sample indications of yield per acre.

From this analysis it may be concluded that when reports are received from a well-maintained and active list of county reporters and these reports are weighted by the importance of the crop in each county, the resulting weighted average of these reports is usually a very satisfactory indication of the average yield per acre in a given State. With generally grown crops such as corn, oats, and wheat, reports for several counties could be missing from any of the large and more homogeneous States without seriously affecting the resulting average of yield per acre. But with crops of highly localized acreage, such as tobacco or cotton in Missouri and Virginia (where they can be grown in only a few counties) there is grave danger that

reports on yield might not be received from one or two counties which would represent from one-half to nine-tenths of the acreage in that State. As a result, the reported yield from the county sample would not be representative of the important producing areas, and it might easily be in serious error.

In the smaller States having only a few counties, a sample containing reports from all the counties would be subject to a very high probable error, and estimates based on such samples would not be reliable. This difficulty is pronounced in the New England States and in the far Western States, where conditions are extremely varied.

Fundamentally the method of estimating the yield per acre of a crop primarily from sample data obtained from voluntary crop correspondents is the same to-day as in 1879, when the acreage and production of crops was first enumerated as a part of the Federal census of agriculture. During the last 50 years the size of the yield sample, however, has been greatly increased.

The development of the crop-reporting service along the lines it has taken has been logical. Additional lists were developed to serve as a check on each other; trained agriculturalists were appointed in each State or group of small States, who could travel and observe crop conditions and make reports which act as a further check on the sample returns. But with the major crops in the important producing States the old system of carefully selected county crop reporters, with from one to five assistants in each county, was a highly efficient method of obtaining a reliable indication of the yield per acre of such crops. It was fully as reliable an indication as the unweighted returns from the larger list of township correspondents started in 1896. In fact, the yield sample from the county list, when that list was well maintained and active, was a much more reliable indication of yield per acre than might be inferred solely from the number of observations.

With generally grown crops, and in fact with practically all crops except the most localized and those the yields of which per acre differ greatly as between counties, the present method of weighting by crop-reporting districts the returns from the township list and those from the list of field-aid reporters is a logical outgrowth of the earlier situation in which there were a small number of weighted reports from the county list and the larger, unweighted sample from the township. Weighted and unweighted averages of the returns from two separate lists are a protection from errors in computation, which must always be guarded against, as well as a means of greatly improving the representativeness of a sample that is not distributed in proportion to its relative importance geographically in a State.

ESTIMATES OF YIELD PER ACRE, 1866 TO 1925

SIZE OF SAMPLE

The year 1866 marks the beginning of the present series of yield-per-acre estimates for important crops by States. From 1866 to 1882 the reports from the county correspondents were practically the sole basis of these yield estimates. Each county reporter was expected to have assistants, not to exceed five, who reported directly to him each month for that part of the county within which each lived. The Department of Agriculture undoubtedly endeavored to keep an active

county reporter in each agricultural county of the United States, but it is not likely that returns were received from more than 60 to 75 per cent of all counties within a State for any one year. The August, 1881, report on cotton condition was based on returns from 56 per cent of the counties in North Carolina and 70 per cent of the counties in Georgia.

For the more important crops in the larger States a sample of this size stratified by counties would be fairly adequate in size, and differences in yield per acre for a given crop from year to year would be reasonably significant from a statistical standpoint. If samples of corn yields per acre in Iowa, in those early years, had had about the same dispersion as in recent years (25 per cent or less), a sample of 46 reports would have resulted in a relative probable error of 2.5 per cent, or with a sample of 71 reports the relative probable erorr would have been 2 per cent, as compared with less than 0.5 per cent with the larger samples now regularly obtained. Samples of cotton yields per acre with a 50-per cent coefficient of variation and 46 reports would have had a relative probable error of about 5 per cent; 71 reports would have reduced it to 4 per cent.

It is probable, however, that greater effort was made to obtain reports from each county when the yield-per-acre inquiries were made than was the case with the monthly condition figures. At least as early as 1872 the returns from the county reporters were weighted by the importance of a given crop in each county. This would bring about an improvement in representativeness, which would contribute more to attaining an accurate indication of yield per acre than a mere increase in size of the sample with crops of localized acreage such as tobacco, potatoes, etc. In the far Western States or in the small States of the East and South the sample from county reporters has been so very small that it would have been of value only as a general indication of the trend of yields per acre over a period of years.

In 1882, State statistical agents were appointed on a part-time basis in most States. Within a year or two these agents began to develop a small list of correspondents who reported directly to them each month. The estimates of the agent were based primarily on the returns he received from his correspondents; consequently the official estimate of the yield per acre of crops for a given State made by the chief statistician in Washington were based on two sources of information (1) the returns from the county correspondents and (2) the estimate of the State statistical agent. The additional reports obtained by the State agents probably doubled the size of the sample in most States. Many sources of information were increased and made available by the State statistical agents. For instance, threshers' returns of bushels threshed and acreage harvested were reported from Ohio. During the eighties, estimates of the yields on a large number of individual farms were obtained for the first time and were used as a check on the other sources of information. Since these yields would be higher than the average for a locality, they were used in a relative sense.[12]

In 1896 the department inaugurated the township list; within a few years this list included about 30,000 correspondents, or approxi-

[12] B. W. Snow, in commenting orally to the writer on the general practice of handling the reports and making estimates in vogue during the years from 1882 to 1892, when he was connected with the department, stated that the returns of the county correspondents continued to be the primary basis of the official estimates and that the estimates of the State statistical agents were used merely as a check.

mately one crop reporter in each township, or the equivalent. The addition of this large number of reporters increased the size of sample several times and undoubtedly materially increased the precision of the averages.

This increased number of reports was especially helpful in securing a sample representative of the crops that had a localized acreage. When there were only county reporters, if the acreage of rye, tobacco, or beans was limited to only a few counties, it might frequently be necessary to make an estimate of the average yield per acre for a State when no reports would be avaliable from the counties in which from 50 to 70 per cent of the crop was grown.

In the beginning the township returns were also weighted by counties, but this required so much labor that for years only a simple arithmetic average of the township returns was calculated. In comparatively recent years the township returns of yield per acre have been weighted by crop-reporting districts. The counties were grouped into crop-reporting districts in the decade from 1900 to 1910, and a system of district weighting was used by the State statistical agents in handling their returns, although some continued to weight by counties.

With the appointment of regional field agents and crop specialists on full time during the period from 1900 to 1910 and the building of lists of correspondents to report to these regional agents the size of yield-per-acre samples was further increased. Weighting by districts was practiced by most of these regional agents.

During the reorganization of the crop-reporting service, in 1914, the positions of part-time and full-time regional and statistical agents were abolished, and a full-time position of State statistician, as it exists at present, was created in practically all States. The appointment of the State statistician was placed under the jurisdiction of the Civil Service Commission, and the requirements were materially raised. There was also a merging of the lists of correspondents who had reported either to the State agent or to the regional agents into what has since been known as the field-aid list, which reported directly to the State statistician in each State. This list was greatly increased in size until it contained more correspondents than did the township list.

The yield estimates during the last 30 years have been based on samples of sufficient size to render the results highly stable except in the far Western States and in some of the smallest States. During the last 15 years the yield estimates have been on practically the same basis from the standpoint of size of sample as the estimates of recent years that were analyzed earlier in this bulletin.

The period from 1866 to 1930 may be divided, on the basis of size of sample, into about four periods as follows:

(1) 1866–1883. Returns were from county reporters only.

(2) 1884–1895. Returns from the county list were supplemented by returns from field aids, who reported to part-time State statistical agents in each State. Individual-farm acreage and production returns were used to some extent on a relative basis as an indication of yield per acre of crops.

(3) 1896–1914. Returns from county correspondents and field aids were supplemented by the addition of returns from the township list of crop correspondents. Regional agents with limited lists of correspondents developed after about 1904. Lists of ginners and other special lists were used in connection with cotton.

(4) 1915–1930. With the reorganization of the field service, the field-aid lists were consolidated, and the size of lists was greatly increased by the State statisticians. The county lists were merged with the township lists in 1925.

REPRESENTATIVENESS

The crop reporters of the department have always been distributed either by counties or townships, and consequently this method of stratifying the sample has always not only aided the precision of the average but also the representativeness of the sample. By 1872 the county reports were being weighted by counties, and this improved the representativeness of the average of the sample. The returns from the field aids were usually weighted by the State statistical agents, by counties, and after the development of crop-reporting districts between 1900 and 1910 these returns were generally weighted by districts. The township returns were so numerous that weighting was not deemed necessary even with important crops until within about the last 10 years. Lack of geographic representativeness has probably not been a serious problem at any time in the case of the more generally grown crops in the States of major production.

BIAS

The understatement of yield per acre on the part of farmers has been a somewhat difficult problem in the case of such an important cash crop as cotton. In the first years of these reports on crop yields the inquiry was made as a percentage of the previous year, and in actual bushels and pounds per acre during the decade from 1860 to 1870. In commenting on these returns the statistician suggests that the yields themselves may be high, as they were obtained from better-than-average farmers, but that the crop reporters were well qualified to estimate the change in yield per acre on a percentage basis. From 1896 to 1925 the averages from samples obtained from county reporters show no tendency to be either higher or lower than those from the township correspondents. Differences between the averages from these two samples could easily be accounted for on the basis of the influence of the fluctuation of sampling or lack of representativeness.

There is apparently a break in the trend of the yield-per-acre series for corn for the United States in the early eighties; this has led many observers to conclude that some shift had been made in the method of estimating corn yields, beginning in 1881. In the North Atlantic States the break is abrupt, and in practically all sections the yields were unusually low during the period from 1881 to 1893. This break in trend was so abrupt that it led Whitney (*17 p. 50*) in his study of the trend of crop yields to conclude that "the only possible explanation is that the department's estimates were adjusted at that time in conformity with the facts determined by the census."

The census for the crop year 1879 made possible for the first time the calculation of a derived yield-per-acre figure from the enumerated production and acreage. In the North Atlantic States, where the break was most in evidence, the differences between the official estimates of corn yields per acre published in the year 1879, and the yields derived from the census were not sufficient to justify any change in method. (Table 37.) In Maine, Vermont, Rhode Island, and New York the yield figures from the two separate sources checked within a bushel. In New Hampshire and Connecticut the census was about 4.5 bushels higher than the department's estimates, and in only three of these States, Massachusetts, New Jersey, and Pennsylvania did the census yields run below the estimates of the department.

The late-season condition figures for corn tend to show somewhat the same trend as the yield estimates. In the November, 1889, crop

report, the chief statistician comments on the corn-yield situation during this period as follows:

> Seven years, 1881 to 1888, which were so lean that only one, 1885, made an average of 26.5, one falling to 18.6 in 1881, made the remarkably low average of 22.9 bushels. The period of 10 years, including the present, will make an average a little above 24 bushels, a reduction of fully 7 per cent from the average preceding 10 years. This is a difference so large, due evidently to meteorological causes and assuredly not to the depletion of fertility or deficiency of cultivation, that a periodic recurrence of such results might soon give some encouragement to the cycle theory.

When the fundamental relationships between weather factors and the yield per acre of corn are eventually worked out for several of these States it will be possible to test this series of yields during the period from 1870 to 1890 and to determine rather definitely whether there was any change in the method of estimating the yields of corn at that time (*16*).

CONCLUSIONS

The methods used by the Department of Agriculture in making estimates of crop production may be classified under three headings as follows: (1) Collection of sample data, (2) field travel and observation by the State statistician, and (3) collection and utilization of check data on quantity of the crop entering the channels of trade.

The present method of collecting sample data from voluntary correspondents is generally successful as a basis for estimates of yields per acre in the case of most crops of extensive acreage in important producing States. The yield estimates for many crops in a number of States could be improved by the further application of the principle of stratification, especially in those States in which conditions are extremely varied or in which crops tend to be localized. The stratification of the State into districts which have greater homogeneity than have the present districts would improve the representativeness of the weighted average for the State and reduce the influence of the fluctuations of sampling.

The township and field-aid lists of crop correspondents have been combined into one list which reports directly to the State statistician in each of several States (Pennsylvania, New York, New Jersey, the New England States, Virginia, West Virginia, Maryland, Delaware, Florida, Nevada, Utah, and California). A similar arrangement in the other Rocky Mountain and Pacific Coast States would tend to improve the accuracy of the estimates in those States. In districts of extreme variation and small samples, a comparison of the reports from the same reporters for two consecutive years would be helpful as a basis for estimating the change in yield from one year to the next.

Post-season inquiries of yields per acre for cash crops with a tendency toward cash-crop bias, such as the present March inquiry on cotton yields (Table 17), might well be extended to other crops such as commercial potatoes, tobacco, peanuts, field beans, and fruit and vegetable crops generally.

A more detailed and critical comparison of official estimates and the sample returns from crop correspondents with the yields derived from census data would throw additional light on the limitations of both the enumeration and the sampling method of obtaining crop yields per acre. It is necessary to determine the limitations of any method before much progress can be made toward its improvement.

A thorough and comprehensive study of yields as derived from the Federal census for the crop year 1929 as compared with the sample returns from the crop correspondents would be highly desirable. The inquiry concerning yields per acre made in connection with the regular April crop report and also an individual-farm inquiry on acreage and production made in the same month, have placed all the sources of yield-per-acre information on the same footing from the standpoint of memory bias. Such a study of the indications of yields per acre for the crops of 1929 might well be a joint study of the Bureau of the Census and the Division of Crop and Livestock Estimates, since both organizations are undoubtedly interested in fundamental research of this kind, which will form the basis of a better understanding of the available data and a starting point for further improvement in methods for both agencies.

On the basis of a scientific analysis of all the information available from both crop reporters and the census, it would be possible to establish yield-per-acre estimates for the crops of 1929 that could be used as a base for annual estimates for subsequent years until the next agricultural census is made.

The suggested annual sample census is needed primarily as a means of estimating changes in acreage and number of livestock on farms from year to year, but it would also serve as an extremely valuable check on estimates of yield per acre, which, with most crops, must be made earlier in the season. In cases in which reliable estimates of yields per acre of crops on a county basis are desired, the suggested sample census would supply the necessary data. The sample census would be especially helpful in those States in which it is now difficult to obtain an adequate and representative sample.

Extensive field travel and observation by the State statistician is essential, especially in States in which conditions are extremely varied and crops are highly localized. The greater the differentiation in a given universe of inquiry, or the smaller the sample, the more important does it become for the statistician to have full, detailed, and up-to-date knowledge of the universe of inquiry.

The importance of obtaining data that can be used as a check on the accuracy of the estimates of crop production can not be overemphasized. Additional facilities are needed for securing this type of information from all classes of common carriers for all agricultural commodities that are sold from the farm.

The results of this study, in common with other economic and statistical generalizations, can not be stated with the precision that is possible in the field of the more exact sciences, but they justify certain general conclusions concerning the adequacy and reliability of the official estimates of crop yields per acre. The relationships involved are complex, and when any factor is mentioned individually, the conclusions should be qualified with the statement "provided other things are equal."

Estimates of crop yields per acre for the 12 North Central or Corn Belt States are not only more reliable than those for any other part of the country, but are about as accurate as such estimates can possibly be when made on the basis of sample data obtained from voluntary crop correspondents. The estimates are least reliable in the Rocky Mountain and Pacific Coast States, and in some of the smaller Eastern and Southern States.

Estimates for such generally grown crops as corn, oats, wheat, and hay which have rather uniformly distributed acreage in the State where they are grown, are usually more reliable than crops of highly localized production such as commercial potatoes, beans, peanuts, and tobacco. The estimates for crops of relative little importance in a given State are much less reliable than are the estimates for the major crops.

Estimates for important and somewhat specialized cash crops, such as cotton, tobacco, commercial potatoes, peanuts, and beans, are likely to be less reliable than are the estimates of crops largely consumed on the farm or in the locality in which they are produced. Fortunately, this situation is not so serious as it might at first appear, as check data of the commercial movement of the crop are obtained for many of the crops that are sold. These check data available over a period of years make it possible for the statistician to correct for bias which may exist in the original sample material.

The explanation of these conclusions is found in the application of the fundamental principles of sampling and of statistical induction under given circumstances and conditions as well as on a direct comparison with yields derived from census data. The estimates for the major crops in the important North Central States are more reliable than elsewhere, as the universe from which the sample is drawn is more homogeneous and there is less dispersion in the yields per acre over a given State than generally prevails in other sections. The size of sample is fully adequate to reduce to a minimum the influence of the compensating errors of observation and the fluctuations of sampling. Most of the important crops in this area are generally distributed over a given State, thereby insuring geographic representativeness of a sample stratified by townships. Cash-crop bias and other forms of noncompensating errors in the individual observations are apparently much less serious than in most other sections of the country. Many of the crops are utilized on the farm, and even with the cash crops, such as wheat, flaxseed, and commercial potatoes, there seems to be little evidence of cash-crop bias. The reliability of the yield estimates from this large agricultural area is of tremendous importance in its effect on the reliability of the estimates of total production of such staple crops as wheat, corn, oats, barley, rye, flaxseed, potatoes, and hay.

The estimates of yield in small States are not so reliable, primarily because it is difficult to obtain a sample of adequate size. Sample data in several of the Rocky Mountain and Pacific Coast States are practically worthless as a basis for estimates of yield without careful interpretation and analysis by a statistician thoroughly conversant with the current situation.

With crops of highly localized production it is usually difficult to obtain a sample that is adequate in size and fully representative. Weighting by counties rather than by crop-reporting districts greatly improves the representativeness, provided there are a sufficient number of reports by counties to prevent possible distortion.

Understatement of the yield per acre on the part of the crop correspondent, found in the yield inquiries made prior to the selling of a cash crop like cotton, can never be eliminated from the sample data and must be allowed for by the statistician in making the estimate. Check data on production or on the quantity of a crop sold, such as cotton ginnings, car-lot shipments of grain, fruits, and vegetables, are

being used to indicate the presence of this cash-crop bias. At present, it is extremely difficult to measure the extent to which this bias existed during past years, because it can not be accurately allocated as between the acreage and the yield-per-acre sample data. It is like a problem in joint costs in accounting. The measurement of bias in yield-per-acre data is contingent on the development of more accurate methods of sampling acreage. Until a fairly accurate measure of cash-crop bias can be developed on the basis of previous experience, this allowance for bias that the statistician is compelled to make is largely a matter of personal judgment and must be made in connection with any statistical inference based upon the type of sample data.

It is difficult to obtain a sample of adequate size in localities in which the farmers are foreigners who do not read and write English readily, in localities in which the general level of education is low, and in communities in which the farms are somewhat isolated. In some States the standard bushel is not the customary unit of measure, and consequently special schedules are used to prevent misunderstanding of the questionnaire.

During the last 20, or perhaps 30 years the estimates of crop yields per acre of most crops have been nearly as satisfactory as during the last 5 years. Prior to 1896 the estimates for minor crops were much less dependable than during the period since then, and they were least reliable during the period prior to 1882.

Estimates of yield per acre for the more generally grown crops could be made with a fair degree of reliability by crop-reporting districts in the important Corn Belt States. To make estimates of yield for minor crops by districts, or for any crop by counties, is not feasible on the basis of the present system of voluntary crop correspondents except in some of the Corn Belt States. Such estimates are necessarily so unreliable that they are being discontinued until such time as the suggested annual sample census becomes an established method of sampling acreage, production, and number of livestock on farms.

The official estimates of yields per acre for generally grown crops in important producing States check sufficiently closely with yield derived from census data, when allowance is made for the inherent limitations of data obtained by the enumeration method, to justify the conclusion that these two entirely separate indications of yield approximate closely the true yield per acre. The difference between these two indications of yield per acre are seldom more than might be expected from the application of the principles of sampling. The statistician must be on his guard against bias in the sample data when making an estimate of yield per acre for cash crops, which are the principal source of income in the localities where produced.

The reliability of the estimates of crop yields per acre is only one aspect of the larger problem of the reliability of the official forecasts and estimates of crop production. This bulletin is in the nature of a progress report; it deals with a phase of sampling that probably has a broader application in the general field of sampling economic phenomena than has any other work being done by the Department of Agriculture. Further work of this kind, now under way, should eventually make available (1) the results of similar studies concerning the sampling of acreage, of livestock numbers, and of retail prices paid by farmers, (2) the results of much more detailed studies relative to the problem of sampling in a given State, and (3) an appraisal of methods used in forecasting crop yields per acre prior to harvest.

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THE VISUAL SPECTROPHOTOMETRY OF DYES

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CONTENTS

	Page		Page
Introduction	1	The identification of dyes	16
Color and absorption	1	The spectroscopic method	17
Color and chemical constitution	3	The spectrophotometric method	18
Equipment and technic for visual spectrophotometry	4	Absorption ratios	21
The influence of conditions upon absorption	8	The spectrophotometric evaluation of dyes	25
Solvent	8	Individual dyes	25
Dye concentration	10	Dye mixtures	30
Temperature	12	Spectrophotometric evaluation and practical dye testing	34
Colloidal state	14	Indicator methods	35
Hydrogen-ion concentration	15	Literature cited	39

INTRODUCTION

COLOR AND ABSORPTION

The phenomenon of color arises from the selective absorption of light in the visible spectrum. The visible spectrum is that relatively restricted portion of the entire spectrum of radiant energy to which the eye is sensitive. The practical working range includes, roughly, the light of all wave lengths between 400 mμ and 720 mμ. (The millimicron, denoted by the symbol mμ, is the millionth part of a millimeter, and is equivalent to 10 Ångström units.)

The color of substances, whether in the solid form or in solution, is determined by the location of their dominant absorption of light within the visible spectrum. Their color is complementary to the color of the light they absorb. A violet dye, for example, appears violet because of its predominant absorption of yellow light. A red dye absorbs principally green light and a blue dye, red light.

The unaided eye perceives but can not analyze color. The color of substances may be of simple origin. It is more commonly of very complex origin, depending upon the varying degree of absorption of light over the extensive spectral ranges. The eye merely registers a composite effect, which may be the resultant of an endless variation of factors. It is possible, however, to resolve this effect into its component factors with the spectrophotometer.

[1] Research fellow supported by the Commission on the Standardization of Biological Stains.

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The spectrophotometer may reveal that two violet dyes which are indistinguishable to the unaided eye may differ very decidedly in the details of their absorption of light. A third dye, which may appear identical in color, may be shown by the spectrophotometer to be a mixture of blue and red dyes, with an absorption spectrum radically different from that of a true violet dye.

The spectrophotometer enables the analyst to measure the degree in which a colored substance absorbs light in all portions of the spectrum. This absorption, in the instance of dyes, usually occurs in well-defined bands. If the measurements are expressed in terms of light absorbed and are plotted against wave length, the analyst obtains an absorption curve or graphical representation of the dye spectrum, which will show the precise manner in which the dye absorbs light throughout the spectrum.

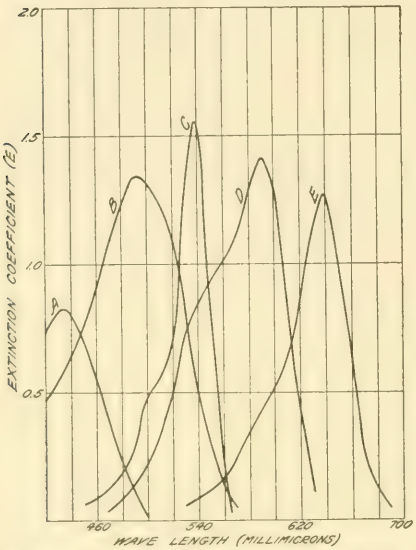

FIGURE 1.—Typical dye spectra: A, Tartrazine; B, orange G; C, phloxine; D, crystal violet; E, Neptune blue

Typical absorption curves of dyes are illustrated in Figure 1.

When measured under suitable conditions, the spectral positions and general forms of absorption spectra are characteristic of individual dyes, and the magnitude of absorptive indices (the height of the bands) is a direct measure of the concentration of dye present.

The advantages of the spectrophotometer over the colorimeter are obvious. It enables the analyst to dispense with comparative standards and express measurements in absolute values. It provides photometric fields for matching which are completely uniform in hue. Whereas the colorimeter merely provides relatively favorable conditions for the visual comparison of total color intensity, the spectrophotometer affords an analysis of color which is not only frequently illuminating in regard to the nature of the origin of the color, but is also of great value in respect to the applications in which it may be utilized.

The term, "depth of color," as employed by the colorist carries no implication with respect to color intensity, but refers entirely to dominant hue. In any series of colored compounds the color of the simplest member is usually yellow. The color of such a compound may be deepened by weighting the molecule with suitable substituent groups, passing from yellow to orange and then from orange to red. In like manner violet is a deeper color than red, and blue is a deeper color than violet. By referring to Figure 1 it will be observed that the phenomenon of deepening color is simply one of the progressive passage of the absorption band through the visible spectrum. When the band first enters the spectrum, the color is yellow. As it passes through the spectrum in the direction of longer wave length, the color

changes successively to orange, red, violet, and blue. Green is a still deeper color than blue. The spectra of dyes are more complex than is apparent from their absorption of visible light. They absorb light in the ultra-violet region of the spectrum as well as in the visible spectrum. The passage of the absorption bands through the visible spectrum with deepening color is accompanied by a corresponding progress of other absorption bands in the ultra-violet. In passing from blue to green color, the second band passes from the ultra-violet into the far-violet region of the visible spectrum. The spectra of green dyes show absorption in the far-violet as well as in the region of red light.

In some instances the absorption bands may progress even farther. The primary band may leave the visible spectrum and enter the infra-red region, in which, of course, it will cease to influence color. The secondary band will then give rise to what is termed "color of the second order."

COLOR AND CHEMICAL CONSTITUTION

It is obvious that the manner in which a substance absorbs light, whether within the visible spectrum or elsewhere, must be related, primarily, to its chemical constitution. Chemists make this assumption in establishing the structure of substances on the basis of the analogy of their spectroscopic characteristics and behavior with that of other substances of known structure.

Countless investigations during the past 50 years have revealed many facts regarding the manner and degree in which minor constitutional variations in dyes influence the spectral locations of band maxima. It has even been found possible to calculate the positions of maxima on empirical principles with considerable success (*48*, *49*).[2] Recent studies of the quantitative aspects of absorption carried on in the Color and Farm Waste Division indicate clearly that an analogous correlation exists between the constitution of dyes and their intensity of color.

Although much has been learned respecting the modification of color by means of constitutional variations, the ultimate cause of color has remained obscure. Simple theories as to the relation between color and constitution have been repeatedly shown to be inadequate for universal application, and no explanation of known facts has replaced them which has met with universal acceptance (*58*).

It is probably the general belief that the vibrations which are responsible for color are electronic. It appears certain, furthermore, that color is conditioned upon factors which can not be expressed by conventional methods of defining chemical structure. There is considerable evidence which indicates that the arrangement of residual affinities of molecules may have a decided effect upon color.

Any protracted discussion of theoretical aspects of color and absorption would be out of place in this bulletin. It is advisable, however, to emphasize one fact. Color is not completely dependent upon constitution in the ordinary sense. The absorption of dyes is affected in appreciable degrees by factors which do not modify structure

[2] Italic numbers in parentheses refer to Literature Cited, p. 39.

as expressed in conventional terms. It is never safe for the color analyst to assume that the absorption of a dye will be identical under different conditions. He should determine by experiment the factors which may affect the absorption of any given dye and base his technic with that dye upon his findings.

EQUIPMENT AND TECHNIC FOR VISUAL SPECTROPHOTOMETRY

The essential principle of the visual spectrophotometer is simple. Two parallel beams of light of equal intensity are passed through a photometer and thence through a spectrometer to reach the eye in contiguous fields, enabling the observer to compare the two spectra accurately. The photometric arrangement provides for the uninterrupted passage of one beam and for the reduction of the intensity of the second beam in any proportion desired. A glass cell containing the solution of the dye which is under examination is interposed

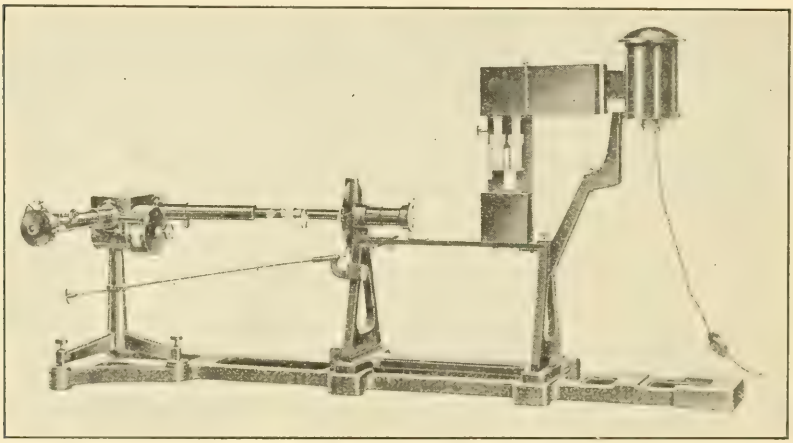

FIGURE 2.—Modern spectrophotometer

in the path of the first beam, and a similar cell containing solvent alone in the path of the second beam. The spectrum of the beam which has passed through the dye solution will be deficient of such light as has been absorbed by the dye, and the light thus absorbed may be measured by reducing the intensity of the second beam until it matches that of the first beam.

Figure 2 shows a spectrophotometer of recent design which is exceptionally convenient for investigating the absorption of solutions of dyes in the visible spectrum. Figure 3 is a schematic diagram of the same instrument.

A 250-watt Mazda projection lamp is employed as the light source. This may be disconnected from the carriage readily if any occasion arises in which it may be desired to employ a light source of a different character.

The absorption cells are removable vertical cups of optical glass, which may be raised and lowered about plungers of optical glass, thus varying at will the depth of the layer of solution through which the light passes. The cells rest upon a platform provided with a

graduated scale and vernier which enables the analyst to measure to one-tenth of a millimeter the depth of the solution layer over the range from zero to 6 centimeters.

This feature of the instrument is a very valuable aid to convenience. It is necessary to restrict absorption within somewhat narrow limits in order to measure it to best advantage. If the analyst employs absorption cells of fixed depth he can only vary and adjust the degree of absorption by the relatively laborious (and sometimes expensive) means of preparing solutions of different dye concentrations. With the calibrated-cup and plunger arrangement, readjustment is possible within wide limits by merely turning an adjusting screw.

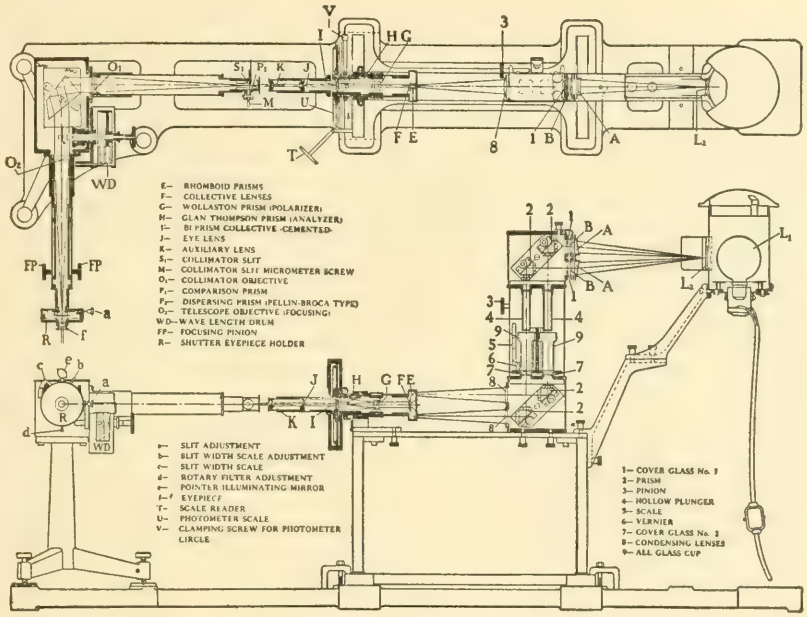

FIGURE 3.—Diagram of modern spectrophotometer

The photometer is of the improved Martens type, depending upon polarization for varying light intensity. The analyzer is rotated by a large circle which is so graduated that the analyst may read from it the angle of rotation or, more conveniently, read directly the transmissive or absorptive values derived therefrom. The photometer field may be reversed to compensate for possible errors arising from polarization within solutions and from minor optical imperfections in the instrument, making the reversal of absorption cells unnecessary.

The spectrometer is provided with a screw drum, calibrated in wave lengths, by means of which the prism may be rotated in such a manner as to bring light of any desired wave length into the center of the field of vision. The eyepiece shutter may be opened wide enough to permit a view of nearly one-third of the visible spectrum or reduced to a narrow slit through which only a narrow

spectral range is visible to enable the eye to concentrate upon obtaining an exact match within that range.

The entire equipment is mounted on a single substantial base, which renders the accidental displacement of the separate units impossible or, at least, improbable.

The same instrument is provided with accessories which enable the analyst to utilize absorption cells in a horizontal position. An illuminating sphere may also be supplied with which the color of colored solid substances may be investigated by comparing the light reflected from their surfaces with identical light reflected from a standard white surface of magnesium carbonate. (The investigation of dyed materials will not be discussed in this bulletin.)

In measuring the absorption spectrum of a dye the wave-length drum is set at a definite wave length, the photometer circle rotated until the light in both visual fields is equal in intensity, and the extinction coefficient read from the circle. Further measurements are then carried out throughout the visible spectrum (or as long as appreciable absorption continues) at intervals of 10 mμ, with intermediate measurements in the region of the dye maximum or in any other portion of the spectrum wherein it may be desirable to bring out detail. If extinction coefficients are then plotted against wave length, a graphic representation of the absorption of the dye, or its absorption curve, is obtained.

In dealing with the absorption of dyes it is very convenient to express spectrophotometric values in terms of extinction coefficients (E). (The terms Bunsen extinction coefficient and absorptive index are somewhat more specific, but are less frequently employed.) The extinction coefficient (E) is the logarithm (expressed as a negative number) of the transmittancy (T). The latter (T) is merely the ratio of the intensity of the light emerging from the solution to the intensity of the light entering it. Such a ratio must necessarily fall between zero and unity. Its logarithm, accordingly, will be negative and will range between zero in the instance of complete transmission ($T=1$) and infinity when extinction is complete ($T=0$). The extinction coefficient is therefore a direct measure of the absorptive power of the solution.

In accordance with Lambert's law (*46*), values of E should increase in direct proportion with the thickness of the solution layer, and in accordance with Beer's law (*1*), they should also increase in direct proportion with solute concentration. Lambert's law is found valid whenever the photometric provisions and technic are satisfactory. Beer's law (*1*) also proves valid in instances in which the conditions are such as will exclude alteration in either the physical or chemical solute molecule.

The use of the spectrophotometer makes but little demand upon technical experience or skill on the part of the analyst. In the matching of the photometric field, in operating the instrument, the most common error on the part of the novice is that of too great deliberation. The average observer will find that he can obtain the most reliable data by making his matches rapidly. (It is assumed, of course, that such readings will be checked repeatedly before final acceptance.) The eye tires rapidly, and its sensitivity decreases greatly with fatigue. It is well for the analyst to match fields as

rapidly as possible and allow the eye a brief period in which to recover its normal sensitivity before attempting to duplicate the first match.

There are two factors which influence visual sensitivity in a decided degree which the analyst should bear in mind at all times. The ability of the eye to recognize differences in light intensity varies considerably both with the wave length of the light and with the degree of illumination. Visual sensitivity is greatest in the yellow-green portion of the spectrum, at about 560 mμ, and decreases somewhat rapidly as either end of the spectrum is approached. Data are available on the relative sensitivity of the average eye in different spectral regions, but it is questionable if they are entirely adequate to serve as a criterion in spectrophotometric practice. It is well for the analyst to determine for himself the spectral range within which his readings may be relied upon, and to determine also, the general order of variation in measurements which he may expect in other spectral regions.

In various practical applications of spectrophotometric data, which will be referred to subsequently, the analyst may have considerable latitude in respect to the wave lengths at which his measurements are carried out. In making his selection the factor of relative sensitivity should be given serious consideration. It may frequently prove advisable to select wave lengths which may involve some measure of disadvantage in other respects in order to effect improvement in the precision of the measurements.

The same consideration may influence the proper choice of solvents and conditions employed. The bands of dyes which may lie in spectral regions in which the eye is relatively insensitive, in such solvents and under such conditions as are ordinarily employed in their examination, may frequently be transposed into more favorable regions for examination by resorting to other solvents or other conditions.

The second factor which influences visual sensitivity is illumination. The eye is most sensitive to changes in light intensity over a limited photometric range, and accuracy suffers with both excess and deficiency of illumination. The analyst should determine for himself the photometric range within which his measurements are most trustworthy and confine his work to it. He may find, for example, that he reads most accurately when the extinction coefficients are approximately 1.00 and that his readings become somewhat less certain when values fall below 0.70 or exceed 1.30. He should, then, modify his technic in such a manner as will enable him to carry out all critical measurements within the photometric zone referred to. With the equipment which has been described, this may be effected readily by the adjustment of layer thickness.

In the outer portions of the visible spectrum, in which sensitivity is relatively poor, better results are obtained with more intense illumination. For this, and other reasons, it may occasionally prove advantageous to replace the heterogeneous light source with a mercury or helium vacuum-tube lamp for work in these regions. It is hardly possible to obtain reliable absorption values with certain yellow dyes unless this is done.

The analyst should know his dyes. He may obtain much information respecting their chemical constitution and general properties

from textbooks and color indices (*52*, *53*). Kayser's review of early spectroscopic investigation (*42*) and Formánek's tables of technical synthetic dyes (*6*) supply considerable detail on qualitative aspects of the absorption spectra of natural coloring matters and commercial dyes. Holmes's tables (*31*) are intended to supplement these sources and enable the reader to obtain whatever information may be available in the literature on both qualitative and quantitative aspects of the absorption of dyes in general. It will be seldom, however, that the analyst will be able to obtain definite information on dyes which will be thoroughly adequate for his purposes. He should know how the spectra of individual dyes are modified by various conditions; on the one hand, in order to avoid inadvertent modifications in absorption which may invalidate his results, and, on the other hand, in order to utilize such modifications in various applications. He will find it necessary, in general, to obtain such information for himself.

The visual method compares favorably in accuracy and reliability with photoelectric and thermoelectric methods over the greater portion of the visual spectrum (*9*). Photoelectric methods are somewhat more satisfactory in the extreme violet and thermoelectric methods in the extreme red.

In the practical applications of spectrophotometric data described subsequently it will be noted that the critical values employed for the most part are ratios. Their validity is conditioned upon relative accuracy in two measurements, rather than upon absolute accuracy of measurements in general. It is believed that this factor will render the employment of the methods less influenced by the type of equipment employed and by the personal equation than would otherwise be the case.

THE INFLUENCE OF CONDITIONS UPON ABSORPTION

It is advisable to discuss the influence which various conditions exert upon the absorption spectra of dyes before taking up any of the specific practical applications which may be made of such spectra. The principal factors which require consideration are (1) solvent, (2) dye concentration, (3) temperature, (4) colloidal state, and (5) hydrogen-ion concentration.

SOLVENT

The earliest investigators recognized that the absorption spectra of colored solutes were affected by solvents even when the solvents themselves were colorless. It was found that absorption bands of dyes occupied somewhat different spectral locations, in general, with each solvent employed in their examination. The rule was formulated by Kundt (*45*) that bands shift toward the region of longer wave length with increasing refractive indices in solvents. The controversy which ensued over the validity of this generalization and its possible interpretation is reviewed and discussed by Kayser (*42*).

Kundt's rule has subsequently been thoroughly discredited. The recorded instances in which the bands of dyes undergo displacement in the opposite direction to that postulated equal or outnumber those of conformity to the rule. Even among the instances in which the

behavior of dyes is in qualitative accordance with Kundt's rule, the degree of displacement with changes in solvent varies greatly with different dyes. The uniformity which would result if purely physical factors were operative is lacking in a conspicuous degree.

The influence of chemical factors upon the phenomenon in question, on the other hand, is readily apparent. Thus, Meek (*47*) has shown that the spectral position of the band of alizarin-cyanine in organic solvents is influenced by the chemical nature of the solvents, and Holmes (*16*) has pointed out that a definite correlation exists between the displacement of dye bands with change in solvents and the constitutional variations in dyes.

The solvents considered in the last-mentioned instance were water and alcohol. Dyes undergoing band displacement in the direction of longer wave length in passing from aqueous to alcoholic solutions were termed "alcopositive"; those exhibiting the reverse behavior, "alconegative." It was shown that a variety of types of substitutions in dyes exert a definite influence upon their behavior in the respect in question, with the effect depending, in some measure, upon the structure of the parent substance and upon the position in which substitution occurs. The effect of substitution within the amino groups in particular is clearly defined with dyes of a variety of constitutional types. Alkylamino substitution exerts an alconegative effect in diphenylmethane, triphenylmethane, rhodamine, azine, oxazine, and thiazine derivatives, whereas arylamino substitution operates in the contrary manner.

It was suggested that these phenomena may find explanation through the hypothesis that the absorption of dyes depends primarily upon the distribution of their residual affinities, and that with solutions of dyes the interplay of residual affinities of solute and solvent results in rearrangements of affinity within the dye molecule whereby their absorption is modified.

It is a logical deduction from this constitutive hypothesis that the behavior of dyes with change in solvent should prove highly individual. This is found to hold true. It appears very probable that the absorption of two dyes is never modified in precisely the same manner and degree in passing from one solvent to another. In instances in which this may appear to occur it seems probable that actual differences exist which are too slight for recognition by available means. In general, appreciable differences are observed. Advantage is taken of that circumstance in differentiating between dyes. When dyes have practically identical absorption maxima in one solvent it is often found that a resort to other solvents will develop sufficient differences in maxima locations to make it possible to distinguish between them.

The normal displacements of dye bands with changes in solvents are relatively small, in most instances amounting to 5 or 10 mμ. When extreme displacements of bands occur it appears probable that radical intramolecular changes have taken place involving definite valence rearrangements.

The displacements of absorption bands with change in solvent are usually accompanied by modifications in the intensity of absorption. In passing from dilute aqueous solutions to dilute alcoholic solutions of rosaniline chloride, for example, the dye maximum not only shifts

from approximately 542 to 548 mμ, but the extinction coefficients of the solutions at their maxima increase by approximately 25 per cent.

It appears probable that such modifications in intensity of absorption may be attributed, primarily, to the same rearrangement in residual affinities of the dyes which has been held responsible for the shifting of the band. In numerous instances, however, the operation of other factors may be recognized. Changes in solvents may modify tautomeric equilibria between dye forms or effect alterations in their state of molecular aggregation. In either instance the dye spectrum undergoes a corresponding modification.

In the specific instance cited, for example, a careful examination of absorption curves reveals the fact that in aqueous solutions of the dye a small proportion of the dye is present in an orange form and that in alcoholic solutions the dye exists entirely in the (normal) red form. It is evident that a part of the increase in absorption at the dye maximum, observed in passing from aqueous to alcoholic solution, is due to the effect of the change in solvent upon the equilibrium between the tautomeric forms of the dye. (P. 11.)

In this particular instance it appears improbable that colloidal change is a contributory factor. It is found that a variety of other salts of rosaniline, including the bromide, iodide, nitrate, sulphate, oxalate, citrate, and benzoate, behave in an analogous manner. They have a common molecular absorption in water, on the one hand, and a different common molecular absorption in alcohol, on the other hand. It appears improbable that such dissimilar compounds should all be equally colloidal in any given solvent, and the conclusion appears warranted that they all give true solutions in both water and alcohol, at all events at the great dilutions employed in spectrophotometric examinations. All the solutions in question, moreover, are spectrophotometrically stable. Their solutions give no indication of alteration in absorption on prolonged standing.

In the transition from solution in water to solution in chloroform, however, these same dye salts behave quite differently. Fresh solutions of rosaniline chloride, bromide, and iodide in chloroform absorb about 8 per cent more light than do their aqueous solutions, whereas fresh solutions of rosaniline acetate and benzoate absorb about 15 per cent less light than corresponding aqueous solutions. The chloroform solutions are unstable in each instance, and the absorption of the acetate and benzoate solutions decreases more rapidly than does that of the chloride, bromide, and iodide solutions. It seems evident that all these solutions are distinctly colloidal, and that the acetate and benzoate solutions are decidedly more colloidal than are the solutions of the other salts referred to.

Colloidal phenomena with dye solutions are discussed subsequently. (P. 14.) They frequently influence the changes in absorption which result from a change in solvent. In all quantitative applications of spectrophotometry, maximum molecular dispersion is favorable to accuracy, and consideration must be given to the selection of solvents which are favorable.

DYE CONCENTRATION

The fundamental basis of all colorimetry is formulated in Beer's law (7) which states in effect that the intensity of color (and absorption) in the solution of a colored solute is directly proportional to the

solute concentration. This law has been tested in innumerable investigations with many solutes and solvents and found relatively unreliable in a large proportion of instances, and the causes of its failure have been the subject of endless controversy. In the following discussion the consideration of its application will be confined to dye solutions.

Dyes are most commonly examined and analyzed in aqueous solution. It is found that comparatively few dyes conform rigidly to Beer's law over any very extensive range of variation in concentration in aqueous solutions, and the behavior of many dyes is decidedly anomalous over even limited ranges of dilution. Such abnormalities in behavior were formerly attributed to electrolytic or hydrolytic dissociation, solvation, or molecular aggregation of solute particles. It seems probable, however, that molecular tautomerism is more frequently the most important factor concerned.

One common type of dye in particular is susceptible of alteration of an extreme order. It has been shown by Holmes (*15*) that aminated dyes of a large variety of constitutional classes undergo radical modifications of absorption spectra with change in concentration in aqueous solution. The typical phenomenon is one of progressive transition between two definite bands of widely separated spectral location. It may be illustrated by a graph showing the absorption of Nile blue 2B at various dilutions. (Fig. 4.) Analogous data have been obtained with more than 100 other aminated dyes.

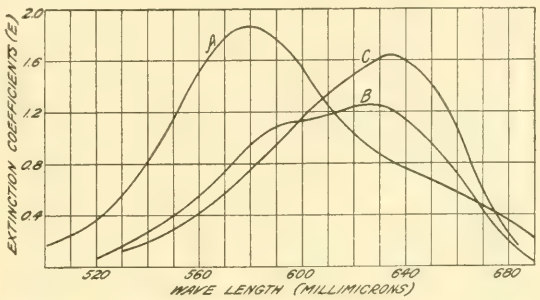

FIGURE 4.—Absorption spectra of Nile blue 2B at various aqueous dilutions: A, 665 mg of dye per liter (0.043-cm layer); B, 20 mg of dye per liter (1-cm layer); C, 0.8 mg of dye per liter (20-cm layer)

Such dyes apparently exist in two different structural forms. Of these forms one exists in the solid dye, and the second is found in alcoholic solutions irrespective of the dye concentration of the solution. In aqueous solutions both forms are found in a state of equilibrium, which alters as the solutions undergo dilution.

The equilibria appear practically unaffected by variation in temperature, hydrogen-ion concentration, or neutral salt concentration. They are decidedly affected, however, by the addition to the aqueous solutions of a variety of organic substances which have diverse chemical characteristics but have the common attribute of unsaturation (*27*). The influence of such substances appears to increase with the degree of their unsaturation. Thus, the effect of allyl alcohol is greater than that of isopropyl alcohol, and the effect of m-phenylenediamine greater than that of its hydrochloride. In a general way these substances exert the same influence upon aqueous solutions of the dyes as does simple aqueous dilution.

It seems probable that this phenomenon is another instance in which the interplay of residual affinity in solute and solvent results in affinity rearrangements within the solute molecule. The modification in absorption is so considerable, in general, that a definite readjustment in valence arrangement seems indicated. A hypothesis, which need not be discussed here, has been suggested respecting the nature of this readjustment (*23*).

It is obvious that these phenomena are of practical as well as of theoretical interest. The dilution ranges in which they occur often coincide with the working ranges in colorimetric practice. In such instances they invalidate Beer's law and give rise to anomalous results. In any application of spectrophotometry to aqueous dye solutions, the analyst should bear in mind the possible interference which may arise from this source. Practical means of obviating the difficulty are discussed on page 28.

The influence of constitutional factors in dyes upon the phenomenon of the modification of their spectra with the dilution of their aqueous solutions is clearly evident. Substitutional variations in dyes may decidedly influence their behavior in the respect in question. Crystal and benzyl violets supply an excellent illustration (*21*). The measurement of dilution effects, accordingly, may sometimes serve as a valuable means of differentiating between similar dyes.

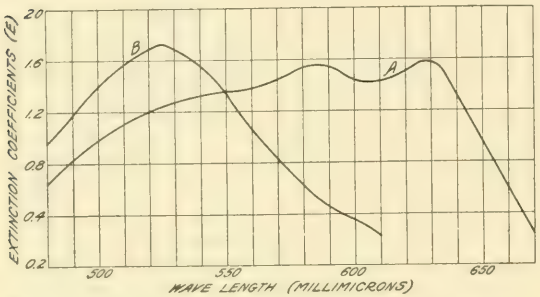

FIGURE 5.—Absorption spectra of Erie violet 3R in aqueous solution (80 parts per million); A, solution prepared with cold water; B, same solution after heating

TEMPERATURE

When Erie violet 3R (NAC) is dissolved in cold water the resulting solution is heterogeneous, containing preponderant proportions of blue and of violet components in addition to the dye proper, which is red. If the solution is then heated, however, or if alcohol is added, the blue and violet components are completely transformed into the dye proper and can not be regenerated subsequently (*12*). (Fig. 5.) It is believed that the blue and violet substances are intermediate compounds in the formation of the true dye. Analogous effects of a less extreme order have been observed with certain other azo dyes, but this type of irreversible alteration has not been reported with dyes of other classes.

It is probably very seldom that the heating of a dye solution results in actual decomposition of the dye. Dye manufacturers warn their customers to exercise caution in resorting to heating in the preparation of solutions of basic dyes, but the basic dyes of some classes appear to be very stable to heat. With basic dyes of other classes, however, the molecule is susceptible to attack at its substituted amino groups. Dealkylation may occur at these points, and amino groups may even, in some instances, be replaced by hydroxyl groups. These transformations proceed very slowly, except under distinctly alkaline

conditions, but are considerably accelerated by heating. Probably few basic dyes would undergo any appreciable degree of alteration of this type in the ordinary course of preparing their solutions by heating, but it is doubtless advisable to bear that possibility in mind.

Only one dye which finds any extensive application is notably unstable to heat. Auramine undergoes hydrolysis very readily in aqueous solutions, particularly under acid conditions (*33*). Solutions of auramine should never be warmed.

Sheppard has observed a very striking type of temperature effect with photosensitizing dyes of the cyanine group (*54*). Increase in temperature gave rise to a progressive transition between one dye band in one portion of the spectrum and a different band in a widely separated location. This alteration was accompanied by changes in the state of solute aggregation and was completely reversible, the original characteristics of the solution being restored when the solutions were cooled. This reversible type of behavior does not appear to have been noted with dyes of other classes.

Radical alterations of dye spectra, however, whether of irreversible or reversible type, are rarely observed in varying the temperature of dye solutions. In general, temperature exerts only very minor effects upon the absorption of dyes.

G. and H. Krüss (*44*) point out that decided changes in temperature may give rise to appreciable errors through their effect upon the optical constants of spectrophotometric equipment. With Bremer (*2*) they investigated the effect of considerable variations in temperature upon the absorption of some 20 dyes. They observed small displacements in the spectral location of bands, occurring in both directions and averaging less than 3 mμ over the extreme temperature range of 60° C., and they also noted appreciable effects upon absorption intensities.

Gibson, McNicholas, Tyndall, Frehafer, and Mathewson (*9*) obtained relatively uniform data with five food dyes which indicate a decrease in absorption over the range between 25° and 40° C. of approximately 2.1 per cent. (Aqueous expansion over this range would account for about 0.5 per cent of the decrease.) An opposite effect was noted with light green SFY, which may probably be attributed to other factors. Their data give little or no indication of band displacements. They concluded that such temperature effects as might be met with in ordinary practice would be insufficient to result in any appreciable inaccuracies in the spectrophotometric examination of the dyes in question.

This conclusion is supported by a limited number of data obtained at this laboratory, principally with azo dyes. It seems probable that the typical temperature effect is a small decrease in absorption unaccompanied by any decided band displacement. The minor variations in temperature incidental to ordinary practice may probably be disregarded, even when solvents are employed with higher coefficients of expansion than that of water.

In spectrophotometric applications with indicators, however, the influence of temperature change upon the dissociation constants of the indicators should be borne in mind, and variations in temperature minimized.

COLLOIDAL STATE

The hypothesis of Stenger (*55*) that radical alterations in the spectral position of absorption bands may be attributed to variations in the size of the physical molecule does not appear tenable in the instance of dyes.

Radical modifications of absorption spectra have, indeed, been found to accompany changes in the state of molecular aggregation in some instances. Apart from the phenomena observed with dyes of the cyanine group, already referred to (p. 13), the instance of indigotine monosulphonate (*14*) may be cited. Such radical modifications of absorption as those are seldom found associated with colloidal change. It is evident that the alteration in both absorption and in colloidal state in such instances must be attributed to molecular tautomerism or some other factor.

It was shown by Pihlblad (*51*) in a study of five selected dyes under a variety of conditions which influence colloidal state, in which spectrophotometric data were correlated with ultramicroscopic measurements, that the spectrophotometric criterion of increasing molecular aggregation is a symmetrical flattening of the absorption band, in which the maximum is depressed and the lower slopes broadened, without appreciable displacement of the band or of its maximum. The same conclusion was reached by Holmes (*15*) in the course of an investigation of dilution effects with aqueous solutions of many dyes. Typical curves in illustration of this effect are given in Figure 6.

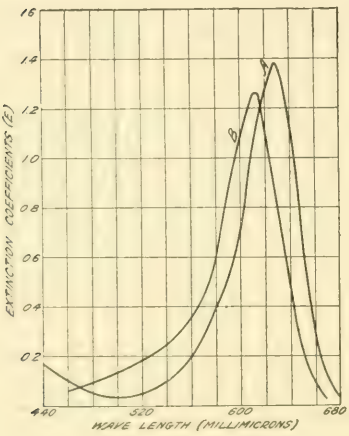

FIGURE 6.—Effect of dilution on the absorption spectra of aqueous solutions of pontacyl green S: A, Very dilute solutions; B, concentrated solutions

The influence which the solvent may have upon the colloidal state of dye solutions (p. 10) has been discussed.

Dye concentration may influence colloidal state in a decided degree. An extreme instance has been reported (*28*) in which the absorption of an aqueous solution of rosaniline phenolate increased by about 28 per cent on dilution with an equal volume of water, instead of decreasing by 50 per cent, as would, of course, be anticipated through the normal operation of Beer's law. It seems probable, however, that with dyes in general such variations in dye concentration as are incident to ordinary spectrophotometric technic will seldom exert any appreciable effect upon the state of solute aggregation.

Neutral salts may modify the spectra of dyes through their effect upon the colloidal state of the solutions. Typical effects are illustrated in Figure 7. The salt effects recorded are immediate ones. Much more decided effects are observed upon the prolonged standing of the solutions.

The effect of such quantities of inorganic salts as may be found associated with dyes in commercial products will be negligible, owing

to the great dilutions at which spectrophotometric examinations of dye solutions are carried out. When, however, the use of buffered solutions is resorted to for the purpose of regulating the hydrogen-ion concentration the dye spectra may sometimes be affected to an appreciable degree.

HYDROGEN-ION CONCENTRATION

Most dyes are stable within the zone of approximate neutrality. Nearly all dyes, however, are modified in constitution, color, and absorption by sufficient concentrations of either acids or alkalies. They are, accordingly, potential indicators of hydrogen-ion concentration, although few of them possess exceptional qualifications for practical application as indicators.

The behavior of dyes with acids and alkalies is influenced by their general structural features and their specific minor constitutional variations. Even minor variations in dyes frequently give rise to decided difference in their dissociation ranges. The measurement of the effect of suitable regulated variations in hydrogen-ion concentration upon the absorption of dyes, accordingly, is often of great service in enabling the analyst to distinguish between them. (P. 19.)

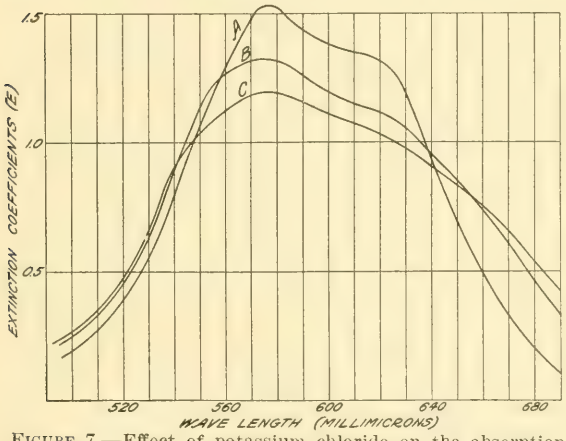

FIGURE 7.—Effect of potassium chloride on the absorption spectra of aqueous solutions of night blue (dye concentration=1 part in 50,000 parts water); A, In distilled water; B, with 0.5 per cent potassium chloride; C, with 1 per cent potassium chloride

The question of the advisability, or necessity, of buffering solutions of dyes intended for spectrophotometric examination, in order to insure a definite hydrogen-ion concentration, is one which may, perhaps, give rise to considerable difference of opinion. It is doubtless necessary to "regulate" the solutions of some dyes in that manner (*17*). In other instances it is unnecessary and entails unfavorable effects. The authors prefer to prepare dye solutions in general for spectrophotometric examination without the addition of buffer agents and to regulate solutions of only such dyes as have been found to be distinctly influenced by minor variations in hydrogen-ion concentration within the zone of approximate neutrality.

It may sometimes prove decidedly advantageous to resort to definite acid or alkaline conditions in the examination of dye solutions in order to transpose absorption bands in the spectrum. This may enable the analyst to carry out measurements in a spectral region in which vision is more sensitive than it is in the region in which he would have to make his measurements on neutral solutions of the same dye.

THE IDENTIFICATION OF DYES

The practical dye tester relies, in part, upon such systematic chemical schemes as that of Green (*10*) and in part upon such reactions and alterations in color with chemical reagents as are cited by Schultz (*53*) or the Colour Index (*52*) for the identification of dyes. He usually has a comprehensive collection of dye samples available for direct comparison, and may sometimes resort to comparative dyeings as a final step in his method. He often acquires great proficiency in the rapid identification of the majority of dyes of principal textile importance.

The differentiation obtained by such means, however, is approximate rather than precise. Even when color reactions are carried out under well-regulated conditions (*32*), they frequently yield results which resemble so closely, as far as unaided visual observation is concerned, those of closely related dyes, that they fail to accomplish the desired purpose. In customary usage they prove notably ineffective. The average dye tester finds it difficult or impossible to distinguish between methyl and crystal violets, for example, or between guinea green B and light green SFY. His rough identifications may prove sufficient for his immediate practical requirements. They are, however, inadequate for scientific purposes.

The resort to more elaborate chemical methods of identification is seldom entirely effective. Chemical methods usually enable the analyst to distinguish readily between dyes which differ radically in structure, but do not ordinarily afford any decisive differentiation between products which differ only in minor constitutional aspects. With dyes in general a more positive identification may be obtained readily by spectroscopic means than is possible by relatively laborious chemical investigation.

With azo dyes only may the superiority of spectroscopic methods of identification be open to question. The absorption spectra of azo dyes, as a class, are somewhat less distinctive than those of other dyes in general, while an exceptionally effective means of chemical investigation is applicable with azo dyes. They may be broken down into their component parts by reduction, yielding the intermediates employed in their manufacture or simple derivatives of those intermediates. The identification of these scission products will serve, in turn, to identify the dyes from which they were derived. Holmes (*20*) has supplied a digest of such data as are available for the purpose. The ability to identify a few hundred amino derivatives, accordingly, will qualify the analyst to identify positively a vast number of azo dyes.

Although this method is one of great possible utility, it appears somewhat doubtful whether it will find very extensive employment. Both the isolation of the reduction products in a suitable condition for identification, and their subsequent positive identification will frequently prove difficult. The labor involved and the technical ability required seem likely to restrict the general use of this method.

There are indications that this reduction method for azo dyes may eventually develop, in large measure, into one of indirect spectroscopic examination. One of the best general means of identifying the reduction products, and one which is increasing in favor, con-

sists of converting them into azo dyes by coupling them with suitable intermediates, and identifying the resulting dyes with the spectroscope. Peter, Mayer, Wegemann, and Marshall (5) and Brunner (4) supply considerable data suitable for that purpose in some of the most important recent contributions to the analysis of azo dyes.

The direct examination of azo dyes by spectroscopic methods is far less difficult and laborious than is the resort to reduction methods. It is probably nearly as effective and reliable in most instances. It would appear preferable, except in instances in which it has been found to be ineffectual or in which the requisite spectroscopic data are unavailable and unobtainable.

With the dyes of other groups, spectroscopic methods almost invariably prove much superior to chemical methods in respect both to convenience and decisiveness. They have the added advantage of being applicable to extremely minute quantities of material.

Spectroscopic methods may be either spectroscopic, in the restricted sense of the term, or spectrophotometric.

THE SPECTROSCOPIC METHOD

The spectroscopic method of dye identification was developed by Formánek (6) through comprehensive study of the light absorption of dye solutions extending over years.

The general characteristics of the spectra of dyes, together with the manner in which they underwent modification with changes in conditions, were found to depend upon the more fundamental structural aspects of dyes. Distinct minor variations in absorption were found with even minor constitutional variation, and usually they proved sufficiently definite to enable the analyst to distinguish between even closely related dyes.

In examining dyes the general type of spectrum and the influence upon it of solvent and dilution were noted. The locations of absorption maxima were determined with great care with a variety of solvents and conditions. Vat dyes were investigated in xylol, tetralin, sulphuric acid, and sulphuric-boric acid. Certain of these solvents were found useful in the examination of dyes of other classes, but with dyes in general the observations were usually carried out on neutral, slightly acid, and slightly alkaline solutions in water, ethyl alcohol, amyl alcohol, and 90 per cent acetic acid.

Part I of Formánek's work (in collaboration with E. Grandmougin and subsequently with J. Knop) is concerned primarily with descriptions of equipment and technic and discussions of such matters as the correlation of color and constitution. Subsequent sections consist largely of compilations of data and incidental information for hundreds of dyes of commercial grades. Sections I and II of Part II deal with soluble green, blue, and red dyes in general; Section III with yellow dyes, and Section IV with vat dyes. Within each general category the subtabulation is based upon the general type of the absorption spectrum and its behavior with changes in conditions.

In identifying a dye of unknown character with the aid of Formánek's tables, the spectroscopist determines the subtable in which it

should be found, and compares the absorption maxima of his unknown sample with those of the various known dyes recorded in it. If his values are in close agreement with those of a known dye, he is justified in concluding that the two dyes are identical beyond reasonable doubt.

The value of the recorded data for purposes of identification necessarily varies with different dyes. The spectra of the dyes of some classes are much less characteristic, in general, than are those of other classes. Individual dyes are encountered, irrespective of dye class, more particularly among yellow, brown, or black products, which absorb light in a manner which is practically devoid of distinctive features. In most instances, however, Formánek's data are reasonably satisfactory for the purpose in view.

The comprehensive character of the tables may be emphasized. It is inevitable that such compilations can not be completely exhaustive, as new dyes are constantly appearing on the market. It is comparatively seldom, however, that dyes are met with in practice which are not to be found in Formánek's tables.

The Formánek system of identification is both rapid and convenient in operation. The proportion of dyes with which it proves useless or seriously ineffective is relatively small, as is that of dyes with which the data necessary for its application have not been provided. It is unquestionably the most valuable means available at present for identifying the majority of dyes with comparative ease and certainty.

The principal objections which can be advanced against the Formánek spectroscopic method are that it places nearly complete reliance upon precise determinations of absorption maxima and that the differences in location between maxima in closely related dyes are often too small to serve as an entirely satisfactory means of differentiation. The precise determination of maxima, moreover, is a matter of considerable difficulty, in which the results obtained may be influenced by the type of equipment used, by the technic employed, and by the personal equation. Commercial products, finally, frequently contain varying proportions of subsidiary coloring matters which may modify their maxima in some degree.

The analyst will frequently find that his data on samples of known identity do not conform exactly with the data of Formánek's tables. He can not rely implicitly, accordingly, upon a comparison of his values with those of Formánek as a means of definitely establishing the identity of his samples of unknown character.

THE SPECTROPHOTOMETRIC METHOD

The spectrophotometric method of dye identification was developed in the Color and Farm Waste Division in the hope and expectation of reducing the uncertainties referred to.

Constitutional variation in dyes influences not only the position of their bands but also the manner in which their spectra undergo alteration with changes in solvent, hydrogen-ion concentration, dilution, and other conditions. The degree of such alteration in consequence of definite modification in conditions is characteristic for individual dyes. It may be determined by measuring extinction coefficients at suitable wave lengths, and may be expressed in terms

of the ratio of such coefficients. In the spectrophotometric method such ratios are employed to supplement data on absorption maxima, and are usually found to afford a much more decisive means of distinguishing between similar dyes than are maxima.

The method has been tested with a group of closely related dyes of the patent blue type (*13*) with one of basic fuchsines (*19*) and with one of basic triphenylmethane violets (*21*).

It may be illustrated by means of the following condensed tabulation of data (Table 1) obtained with certain of the more closely related acid dyes of the patent blue class.

TABLE 1.—*Spectrophotometric constants of dyes of the patent blue type*

Dye	λ [1] in—			Ratio of E at λ [1]—		
	91 per cent alcohol	Neutral aqueous solution	Alkaline aqueous solution	In concentrated aqueous solution to E at λ in dilute aqueous solution	With 0.1 per cent NaOH (after standing) to E at λ in neutral aqueous solution of same dye concentration	With 2 per cent H_2SO_4 to E at λ in neutral aqueous solution of same dye concentration
	mμ	mμ	mμ			
Patent blue A (C. I. No. 714)	630	637.5	627.5	0.76	0.58	0.30
Patent blue V (C. I. No. 712)	630	637.5	627.5	.98	.85	[2]
Alphazurine A [3]	630	637.5	637.5	.77	[2]	.24
Xylene blue AS (C. I. No. 763)	630	637.5	637.5	.79	[2]	.315
Xylene blue VS (C. I. No. 672)	632.5	640	640	.97	.21	[2]
Alphazurine 2G [3]	631	640	639	.96	.34	[2]
Alphazurine (C. I. No. 671)	628	630	630	.81	[2]	.37

[1] λ denotes the wave length of maximum absorption.
[2] Nil.
[3] Alphazurine A and alphazurine 2G have ethylbenzyl and diethyl substitutions, respectively, at the amino groups and a 2,5-disulpho substitution in their nonaminated nuclei.

The values of the second, third, and fourth columns are approximate absorption maxima of the dyes in (1) alcoholic, (2) neutral aqueous, and (3) alkaline aqueous solutions. Those of the last three columns are spectrophotometric ratios, or ratios of extinction coefficients at suitable wave lengths measured under definite variations in conditions. Their variations in value afford a quantitative index of alteration in the dyes under those conditions. The values in column 5 are affected by tautomeric alteration in the dyes resulting from measured variation in dye concentration. Those in column 6 measure resistance to decolorization by alkali, the recorded data indicating the proportion of the dye which withstands the effect of 0.1 per cent of sodium hydroxide over an extended period. Those in column 7 indicate the proportions of dye which withstand immediate conversion into yellow polyacidic derivatives with 2 per cent sulphuric acid. The original paper should be consulted for further detail.

The general principle of such ratio application may be clarified by a more detailed illustration of the significance of the values recorded in column 7. The curves of Figure 8 enable the reader to visualize the effect of acid upon pontacyl blue A (which is identical

with the xylene blue AS referred to in Table 1). The effect of 2 per cent sulphuric acid is measured by dividing the extinction coefficient of an acid (2 per cent) solution of the dye at 637.5 mμ by the extinction coefficient of a neutral solution containing the same quantity of dye at the same wave length. The other dyes of the group undergo analogous transformations, but their degree of transformation at any definite hydrogen-ion concentration is different.

It is of interest to note that such constitutional variation as is found in this group of dyes has a decidedly greater effect upon the general properties and behavior of the dyes than upon their color. The utility of the ratios for differentiation arises from that circumstance.

FIGURE 8.—Effect of sulphuric acid upon pontacyl brilliant blue A: A, 40 parts of dye per 1,000,000 parts of water; B, 100 parts of dye per 1,000,000 in 1 per cent sulphuric acid; C, 100 parts of dye per 1,000,000 in 2 per cent sulphuric acid; D, 100 parts of dye per 1,000,000 in 4 per cent sulphuric acid

Although any constitutional variation doubtless exerts some influence upon the position of the band in the spectrum, the effects in these instances are relatively small. Leaving out of consideration alphazurine FG, which differs from the remaining dyes in both the number and nuclear position of its sulphonic acid groups, it will be seen that the absorption maximum is but little affected by (1) variation in the relative position of sulphonic groups within the nonaminated nucleus, by (2) the introduction of a hydroxyl group therein, or even by (3) the type of amino substitution; that is, whether the diethyl or the ethylbenzyl substitution is involved.

On the other hand, the influence of these constitutional factors is plainly evident in the ratio values. Upon dilution the dyes with diethyl amino substitution behave very differently from those with ethylbenzyl substitution. Their ratios (four) range from 0.96 to 0.98 as against a range of 0.76 to 0.79. They are also decidedly more stable to alkali and less stable to acids. The introduction of a hydroxyl group into the nonaminated nucleus confers indicator properties. It has little effect upon stability to acids but increases stability to alkali materially. Within the nonaminated nucleus the 2,4-disulpho substitution is more stable to acidity and less so to alkalinity than is the 2,5-disulpho substitution.

With these dyes the ordinary chemical methods of differentiation are practically useless. Identification on the basis of absorption maxima alone is also unsatisfactory. It would probably prove both difficult and uncertain even for an expert provided with the most favorable equipment for the purpose.

The value of the recorded ratios for differentiating between the various dyes will be obvious. Xylene blue VS may be distinguished from alphazurine 2G by means of its behavior under alkaline conditions, alphazurine A from xylene AS through its behavior under acid conditions, and patent blue A and V behave very differently with both alkalies and acids as well as upon mere dilution. In each of these instances it is extremely difficult to distinguish with any certainty between the dye pairs referred to by means of absorption maxima alone.

Such ratios may be determined with relative ease and substantial accuracy with any type of spectrophotometer, and the results obtained are independent in large measure of the equipment employed, of the technic followed, and of the skill of the analyst. There can be no doubt that they will be found a very valuable aid in the identification of dyes in general, and will frequently afford a more reliable and precise differentiation between similar dyes than is possible by other means.

ABSORPTION RATIOS

There are definite limitations to the accuracy with which it is possible to determine the locations of absorption maxima on the basis of a mere direct comparison of extinction coefficients. The analyst determines that the maximum must lie between certain limits, say, between 540 and 550 mμ. It is seldom, however, that the spectrum is sufficiently well defined to enable him to state positively that the maximum falls at a definite wave length, say at 545 mμ. The heads of dye bands are usually somewhat flat. In most instances in which he reports a value of 545 he is by no means sure that the true value may not be, rather, 544 or 546 mμ. In some instances even less definite conclusions are possible.

In applying the spectrophotometric method of identification to basic violets of the triphenylmethane group (*21*), determinations of maxima were supplemented by determinations of a spectrophotometric ratio of a type different from those hitherto referred to. Wave lengths were selected on opposite slopes of the bands of the dyes and ratios of extinction coefficients of solutions at these points obtained. Although the conditions chosen in that particular instance were not ideal for the purpose, it was found that the ratios obtained provided a much better means of distinguishing between the dyes in question than did the dye maxima.

The term "absorption ratio" was adopted, subsequently, for a ratio of this type. It may be defined as the ratio of the extinction coefficients of a solution of a colored substance at two specific wave lengths. If the wave lengths in question are selected on opposite sides of the absorption maximum, the absorption ratio defines the spectral location of the absorption band. If they are selected on the same side of the maximum (as may be necessary in visual measurements on yellow dyes) the absorption ratio defines the gradient of the slope of the band within the region of measurements. The slope of an absorption band is usually less characteristic than its spectral location.

The application of the absorption ratio may be seen by reference to Figure 9.

The curves represented are related in the manner which is usual between curves of dyes of similar structure which differ only in minor constitutional aspects. Dyes A, B, and C may be distinguished by their maxima, which are, respectively, 590, 595, and 600 mμ. They may also be distinguished on the basis of absorption ratios. If the ratio adopted be that of extinction coefficients of their solutions at 580 mμ to those at 610 mμ, the ratio values of A, B, and C will be found to be, respectively, 0.88, 1.13, and 1.48. The range of variation in absorption ratio values is much greater than that in maxima values.

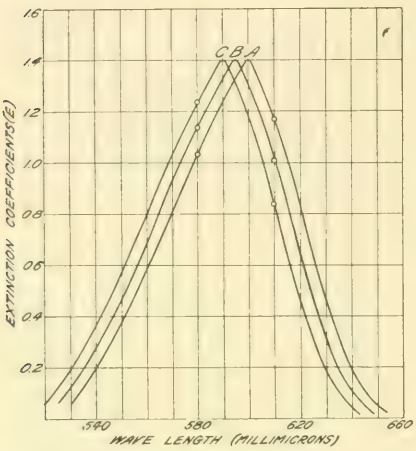

FIGURE 9.—Representative absorption spectra of closely related dyes

In the particular instance illustrated it would not be difficult to differentiate between the dyes on the basis of their maxima, but the heads of the bands of dyes are sometimes so poorly defined that it may be difficult to distinguish between maxima even when bands are as widely separated as those illustrated. Even when dealing with dyes which have clean-cut spectra, the maxima method has definite limitations. If the existence of a fourth dye, D, be assumed, the band of which lies 1 mμ farther toward the region of longer wave lengths than does that of dye B, it is evident that its maximum will fall at 596 mμ and that it will be difficult or impossible to distinguish between it and that of dye B with any certainty. Its absorption ratio value, however, will be 1.20, which can be distinguished readily from 1.13, the ratio value of dye B.

Holmes and Peterson (*34*) have tested the value of absorption ratios as a means of identification in an investigation of 90 dyes employed in biological staining. (Table 2.)

TABLE 2.—*Absorption ratio of various dyes (33)*

Dye	Color Index No.	Solvent [1]	Wave lengths	Absorption ratio [2]
			mμ	
Fluorescein (sodium salt)	766	+5 drops 1 per cent Na_2CO_3	500, 530	36.5
Auramin	655			30.0
Martius yellow	9			21.0
Orange G	27			5.46
Resorcin yellow	148			3.61
Chrysoidin Y	20			2.83
Chrysoidin R	21			2.63
Sudan I	24	95 per cent alcohol		2.49
Bismark brown Y	331			2.20
Orange II	151			1.95
Orange IV	143	+10 drops 6N HCl		1.75
Bismark brown R	332			1.58
Congo red	370			1.22
Purpurin 4B	448			1.19
Vital red	456			1.17

See footnotes end of table.

TABLE 2.—*Absorption ratio of various dyes (33)*—Continued

Dye	Color Index No.	Solvent [1]	Wave lengths	Absorption ratio [2]
			mμ	
Sudan III	248	95 per cent alcohol		1.10
Crystal ponceau	89			1.04
Biebrich scarlet	280			1.00
Orange I	150	1 per cent Na_2CO_3		1.00
Fast red A	176		500, 530	.97
Methyl orange	142	+10 drops 6N.HCl		.97
Sudan IV	258	95 per cent alcohol		.94
Erie garnet B	375			.94
Bordeaux B	88			.88
Dibromofluorescein		+5 drops 1 per cent Na_2CO_3		3.84
Mercurochrome		do	505, 535	2.83
Eosin	768	do		.93
Janus red	266		510, 540	1.12
Amaranth	184			1.07
Eosin B	771	+5 drops 1 per cent Na_2CO_3		1.41
Phenosafranin	840			1.13
Erythrosin	773	+5 drops 1 per cent Na_2CO_3		1.04
Safranin	841			1.02
Phloxin B	778	+5 drops 1 per cent Na_2CO_3	515, 545	.97
Methyl eosin	769	do		.96
Ethyl eosin	770	do		.86
Neutral red	825	+5 drops acetic acid		.75
Methylene violet 2R	842			.61
Rhodamin S	743			1.51
Pararosanilin	676			1.13
Neutral violet	826	+5 drops acetic acid		1.05
Magenta II				.96
Rosanilin				.89
Acid fuchsin	692	95 per cent alcohol	530, 560	.81
Pyronin G	739			.80
Rhodamin G	750			.78
New fuchsin	678			.76
Rhodamin B	749			.58
Pyronin B	741			.52
Rose Bengal 3B	779	+5 drops 1 per cent Na_2CO_3	540, 570	.92
Alizarin red S	1034	N. NaOH		1.21
Alizarin	1027	do	545, 575	.81
Chrome black F	299			.94
Magdala red	857			.90
Meldola's blue	909		560, 590	1.13
Methyl violet	680			1.405
Iris violet	847			1.29
Benzyl violet	683			1.14
Anilin blue (spirit soluble)	689		575, 605	1.08
Crystal violet	681			1.065
Nigrosin (water soluble)	865			1.01
Ethyl violet	682			.91
Thionin	920			1.44
Cresyl violet (Grübler)				1.20
Anilin blue (water soluble)	707			1.08
Trypan blue	477			1.08
Niagara sky blue	520		590, 620	.99
Methyl blue	706			.97
Methylene violet (Bernthsen)				.835
Indigotin	1180			.79
Victoria blue B	729			1.18
Night blue	731			1.04
Cresyl blue (NAC)	877		605, 635	.90
Malachite green	657			.83
Fast green FCF				.76
Guinea green B	666			.72
Brilliant green	662			1.51
New methylene blue N	927			1.21
Cresyl violet (NAC)				1.16
Toluidin blue O	925		620, 650	1.04
Light green SFY	670			.98
Methyl green	684			.91
Nile blue A	913			.90
Methylene green	924			1.12
Janus green	133			.97
Nile blue 2B	914		635, 665	.93
Methylene blue	922			.59
Thionin blue	926			.51
Capri blue GON	876		650, 680	1.27

[1] Unless otherwise specified, the solvent used was 50 per cent water and 50 per cent of 95 per cent alcohol. Any addition to the standard solvent is indicated by +.

[2] The absorption ratio was calculated by dividing the extinction coefficient obtained at the shorter wave length specified by that obtained at the longer wave length.

In general, the solvent employed was 50 per cent water and 50 per cent of 95 per cent alcohol. (P. 29.) (As was to be anticipated, the ratios proved less satisfactory when dealing with yellow, orange, or brown dyes than with dyes of other colors, and less satisfactory with azo dyes than with the dyes of other classes. The accuracy with which they could be determined depended, naturally, upon relative visual sensitivity within the region in which it was necessary to undertake the measurements. Under the least favorable conditions encountered results varied by as much as 1 or 2 per cent, but an excellent agreement in values was generally obtained.

It was found that absorption ratios alone were ample for the purpose of differentiating between the dyes investigated, and unquestionably they provide an exceptionally convenient and valuable means for identifying dyes in general, although it may prove advisable to resort to other methods for corroborative evidence.

With some of the dyes examined, different samples from different sources proved substantially uniform. With numerous dyes, however, different samples gave some diversity in values. Obviously the nature of the absorption ratio is such that its values with any given dye will usually be affected by the presence of other dyes. Most commercial dyes contain varying proportions of subsidiary coloring matters which have ratio values decidedly different from that of the dye with which they are associated. Such color impurities modify the ratio values of the dyes with which they occur in a degree corresponding with the proportion in which they are present.

It might appear that this circumstance would invalidate the use of absorption ratios, or would at least detract seriously from their practical utility for purposes of identification. It seems probable, however, that the proportion of subsidiary dyes will seldom be large enough to obscure the identity of the principal dye. The differences in ratio values between different dyes are so considerable, in general, that the danger of erroneous conclusions is small. The analyst will usually recognize the dye with which he is dealing and realize that he has to do with an abnormal sample of that dye.

The same circumstance, on the other hand, is of great service to the discriminating analyst who is interested in the nature of his samples, apart from the mere identity of the principal dye present. The absorption ratio is an excellent criterion of dye purity, in the restricted sense of purity from contamination with other coloring matters. The deviation of values may frequently enable the analyst to estimate the proportion of subsidiary dyes present within somewhat narrow limits. (P. 34.)

A simple absorption ratio, accordingly, which may be determined easily within a few minutes, is not only an effective means for establishing the identity of dyes, but at the same time it may also furnish considerable information respecting their purity, which could be obtained by other means only with difficulty, if at all.

Absorption ratios have also been found of value as a criterion of dye purity in the synthesis and purification of dyes in the Color and Farm Waste Division. They may be determined readily with material at any point in the process, and they enable the chemist to follow the course of his operations intelligently. If recrystallization effects the removal of a subsidiary dye, for example, the absorption ratio

will indicate that fact and will also inform the chemist when the elimination of the impurity in question has been made as complete as is possible by the means employed. No other criteria are as easy to apply for the purpose or have as wide a range of application.

It will be obvious that the methods of dye identification outlined are applicable not only with dyes but also with a great variety of colorless substances which are of such a character as will enable the analyst to convert them readily into colored substances. The phenols, as a class, supply an excellent illustration. They were converted into phthalein dyes by Gsell (*11*) and by Formánek and Knop (*7*); into azo dyes by Palkin and Wales (*50*, *57*), and into indophenols by Gibbs.[3] In each instance spectroscopic means were employed to identify the resulting dyes. Their identification serves, in turn, to identify the phenols used in their preparation.

THE SPECTROPHOTOMETRIC EVALUATION OF DYES

INDIVIDUAL DYES

The employment of the spectrophotometer for the quantitative estimation of dyes is very simple in theory. The Bunsen extinction coefficients of any dye solution vary in direct proportion with the concentration of dye. When standard absorption data have once been obtained on solutions containing a known concentration of a dye the analyst can determine readily the concentration of other solutions of that dye (in the same solvent) on the basis of comparison of its absorption data.

This statement is completely valid, of course, only in instances in which the normal operation of Beer's law is the sole determining factor. It has already been pointed out that a variety of other factors may be encountered in general practice which influence the absorption of dyes. It is obvious that these may give rise to appreciable errors in the evaluation of dyes unless the technic followed and the conditions provided are such as will preclude such a possibility.

The first requirement for spectrophotometric analysis is that of standard data. In some instances, perhaps, the analyst may be concerned merely with relative values, as is the practical dye tester. In general, however, he will require absolute data. It is impossible to calculate the extinction coefficients which solutions of a given dye will have. They have to be determined experimentally.

Although some data are available in the literature on the quantitative absorption of certain dyes, they seldom can be relied upon, unfortunately, for purposes of quantitative analysis. Even when otherwise adapted for analytical needs, they are usually supplied with so little information respecting purity of material and precise technic that the analyst can not feel assured of their dependability or of the exact conditions which their use demands. It is always advisable, and it is usually necessary, for him to obtain his own standard data in order to insure reliable results.

The first requisites for that purpose are samples of known dye. Absolute purity is seldom attainable, nor is it necessary. The presence of moisture, inorganic salts, or colorless organic substances is

[3] Unpublished investigations.

immaterial. The essential requirements are that the sample shall be substantially free from foreign coloring matters and that its actual dye content shall have been determined by reliable methods.

Purification from color impurities is obtained by recrystallization, separation with immiscible solvents, or other treatments adapted to the requirements of specific instances. The results of such treatments may be followed with the spectrophotometer. Substantial freedom from color impurities may be assumed when further treatment ceases to modify the precise form of the spectrum. More simply, it is indicated by a constant absorption ratio. (P. 21.)

The dye content of samples should usually be determined by means of titration with a standard titanous chloride solution (*43*). This reduction method is applicable with most dyes and is exceptionally convenient. The presence of such foreign substances as are ordinarily found associated with dyes is immaterial. The reduction method is direct, requiring no preliminary standardization in operation. It is seldom that other chemical methods of dye analysis are equally suitable or satisfactory, although it may prove advisable or necessary to resort to them in specific instances.

If resort is made to other chemical methods of analysis it is well to make certain that the dye samples with which they are employed are free from interfering substances. The experience of Holmes and Peterson (*35*) with neutral red and the pyronines may be cited. With these dyes, which can not be evaluated by the reduction method, it was found that all available samples contained appreciable proportions of organic dye intermediates, which invalidated results obtained by other chemical methods. In order to obtain material of known dye content it was necessary to eliminate these organic impurities. This was effected by repeated crystallization. The material was analyzed and examined with the spectrophotometer after each crystallization, and the results of chemical analysis were accepted as reliable only when a constant ratio had been obtained between extinction coefficients and apparent dye content as indicated by chemical means.

It is obvious that the method employed in obtaining standard data should be the same as that which is used subsequently in the evaluation of the same dye. It is improbable that any analyst would deliberately employ different solvents in the two instances. It is, however, quite possible that he might minimize the necessity for uniformity in seemingly immaterial details of practice. Minor details of manipulation are of little consequence when dyes give true solutions in the solvents employed. When dyes have decided colloidal tendencies in the solvents used, however, minor variations in manipulation may frequently lead to appreciable variations in results.

Let us suppose, for example, that it is intended to evaluate a dye on the basis of its extinction coefficients in 50 per cent alcohol. With colloidal dyes it will be found that the absorption values of their solutions may differ decidedly depending upon whether (1) a stock solution is prepared in 50 per cent alcohol and diluted with the same solvent, or (2) an aqueous solution is made up and diluted with alcohol, or (3) an alcoholic solution is made up and diluted with water. It may also be found that different values are obtained, depending upon whether or not a resort is made to heating in order to insure

complete solution of dye in the stock solution. It will be found, finally, that it may matter decidedly whether the absorption readings are taken immediately after the preparation of the solutions or somewhat later, for example, over the week-end.

In such instances the physical state of the freshly prepared solution may vary considerably in accordance with the method of its preparation. Physical readjustment ensues, but may often require a period of days or weeks for completion. It is not feasible for the analyst to wait until the final state of physical equilibrium has been reached. The only practicable course is that of carrying out the absorption measurements upon freshly prepared solutions, and depending upon a strict adherence to a rigid technic in their preparation to insure uniformity in results.

The indirect method of preparing solutions for examination (that is, by dilution of a stock solution) should be followed unless only minute quantities of material are available. With many technical dye products it is necessary to start with several tenths of a gram of dye in order to insure obtaining a representative sample.

The choice of solvent is of the greatest importance. No single solvent, unfortunately, is suitable for employment with all dyes.

A digression seems advisable at this point in order to consider the bearing which the general character of the analyst's work may have upon his choice of solvent and technic.

If the analyst is concerned merely with the evaluation of solutions of individual dyes, it will be advisable for him to investigate the general question of solvent and conditions with some care. The solvent selected should, if possible, be one in which the dye will be completely dispersed. If any regulation of hydrogen-ion concentration is necessary or advisable the provisions adopted should be such as will allow of minor inadvertent variation in conditions with safety; that is, the point selected should lie within a pH range in which the dye is chemically stable. The technic followed should be one which has been tested and found to give reliable results with the particular dye in question.

If the analyst is concerned with the analysis of dye mixtures as well as with that of individual dyes, this course, unfortunately, is not sufficient. Standard absorption data are valid only when the exact conditions under which they were obtained are duplicated. Mixtures of dyes can be analyzed only when standard data are available which have been obtained with the component dyes of the mixture under the same conditions as are utilized in examining the mixture.

It is well, accordingly, for the analyst to obtain standard data on dyes by two methods—a specific and a general procedure. The specific method may then be employed to best advantage when the dye is alone. The general method will probably give somewhat less reliable results, but will enable the analyst to evaluate the dye when it is in dye mixtures.

Aqueous solutions have been employed somewhat generally in the spectrophotometric evaluation of dyes, but their use has unquestionably resulted in many inaccuracies. The authors have pointed out that many dyes undergo tautomeric alteration with variation in concentration in aqueous solution. These alterations frequently occur over the range of concentration within which measurements are usually carried out in analytical practice. The data of French (*8*)

on aqueous methylene blue solutions illustrate the magnitude of errors which may arise from this source.

It has been customary in spectrophotometric analysis to depend upon a comparison of extinction coefficients at or near the dye maximum in solutions which may differ decidedly in actual dye concentration. The analyst, for example, has determined that a 1-centimeter layer of an aqueous solution of methylene blue containing 10 milligrams of actual dye per liter has a certain extinction coefficient at 673 mμ. He measures the extinction coefficient of a 1-centimeter layer of a second aqueous solution of the dye at 673 mμ and finds its ratio to his standard data to be 70:100. He concludes that the concentration of actual dye in the second solution is 7 milligrams per liter. In reality, however, it is appreciably less.

In this instance the analyst is dealing with a mixture of two dye forms, the relative proportions of which are altered with every change in actual dye concentration, rather than with a single dye form. His measurements are carried out in a region in which one dye form absorbs light much more strongly than does the other. The relative proportion of the strongly absorbent dye form increases upon dilution. His extinction coefficients have no fixed relation to actual dye content. If the solution he is evaluating is more dilute than that with which he obtained his standard data, his results (indicated dye contents) will be too high. If he employs more concentrated solutions, his results will be too low.

There are a variety of ways in which this difficulty may be obviated. The analyst may adopt the principle of carrying out all critical measurements at nearly identical concentrations of actual dye. This, however, would necessitate means whereby solution layers could be varied and measured with precision, or would involve the repeated preparation of dye solution. The latter course is inapplicable, moreover, when dealing with dye mixtures. The analyst may employ his usual technic and standardize his extinction values against dye content experimentally over such a working range as might be encountered in general practice; but this course would prove decidedly laborious. He may employ his usual technic without standardization by determining the particular wave length at which both dye forms have the same absorption and at which, accordingly, the relation of the extinction coefficient is unaffected by variation in dye concentration. (P. 30.) Although data obtained at this wave length would prove adequate for the evaluation of dye, it is desirable to have reliable data at other wave lengths for employment with dye mixtures.

The only thoroughly adequate and satisfactory course appears to be to avoid the use of aqueous solutions in general practice.

The phenomenon of tautomeric alteration in dyes with changing concentration is seldom encountered in alcohol, and alcohol has other advantages as a solvent. With aqueous solutions of basic dyes, adsorption of dye base occurs on the surface of containing vessels and absorption cells in varying degrees, depending upon the nature of the dye, the composition of the glass, and other factors. With aqueous solutions of safranines, for example, a 10 per cent decrease in absorption values, arising from this cause, has been observed repeatedly when solutions were left in the absorption cells for about

45 minutes. This type of adsorption is not encountered, or is negligible in proportion, in alcoholic solutions.

The use of 90 per cent alcohol has been recommended for employment with dyes which undergo tautomeric alterations in aqueous solution and with basic dyes in general (*25*). It will be found, however, that 50 per cent alcohol is nearly as effective in stabilizing dye solution to variations in dye concentration and in minimizing adsorption. It is decidedly more economical in use, and for many dyes it is probably even preferable to a solvent with a higher content of alcohol.

The use of 50 per cent alcohol has proved very satisfactory with dyes in general, and the writers have little hesitation in advocating its employment in a general technic, intended for application in particular with dye mixtures. It is suggested that it be used both for the preparation of the stock solution and for its dilution. Although it is an effective solvent for most dyes, it may be advisable to warm the stock solutions of some dyes to promote solution. It is suggested, accordingly, that all stock solutions be warmed in their preparation to insure uniformity in that respect. The addition of buffering agents to insure a definite hydrogen-ion concentration is not advocated. Dyes dissolve less readily in buffered solutions, and their colloidal tendencies are accentuated in them. Definite regulation of hydrogen-ion concentration is essential only with a few dyes. It is suggested, finally, that in all instances absorption measurements be made on the freshly prepared solutions.

It will be understood that this practice will not prove suitable in the examination of all dyes. It is not advocated for use with any individual dye, although it will usually prove reasonably suitable. It is recommended only for general use in the field of the analysis of dye mixtures in which the use of a single technic is requisite which will prove comparatively reliable with dyes of many different classes and types.

In obtaining standard absorption data it is well to carry out measurements throughout the visible spectrum. The standard spectrum obtained will enable the analyst to detect the presence of appreciable quantities of foreign coloring matters when found in future samples, and will also provide him with all the data he may require in the evaluation of dye mixtures. For the analysis of individual dyes he will require values obtained at one, two, or three wave lengths. These should be selected at or near the wave length of the dye maximum rather than upon the slopes of the absorption curves, since the disturbing influence of foreign dyes, which may be encountered in practice, may prove more serious in the latter instance. With yellow dyes, however, it usually will be necessary to deal with band slopes. This course may also prove very advisable whenever dye maxima lie near the extremes of the visible spectrum. In such instances the advantage of improving photometric sensitivity would outweigh all other considerations.

Although the spectrophotometric method of dye analysis is somewhat less accurate with some dyes, particularly with most yellow dyes, than is the reduction method with titanous chloride, it compares favorably with the latter method with dyes in general. When the provisions of the technic are judicious it gives reliable results with most dyes. It may be employed with some dyes to which the

reduction method of evaluation is inapplicable. It may, if necessary, be applied to extremely small quantities of material.

It is, perhaps, unnecessary to add that the spectrophotometer may be utilized to considerable advantage in connection with many of the color reactions which the analytical chemist employs. A single illustration will be cited. It was recently shown that the familiar turmeric test for boron could be modified in such manner as would render it possible to follow its operation with the spectrophotometer, and the results obtained indicated that it would prove possible to detect thereby the presence of 1 part of boron in 25,000,000 parts of aqueous solution (*29*).

DYE MIXTURES

Spectrophotometric methods have exceptional utility in the analysis of dye mixtures. It has been found possible to analyze certain simple mixtures of dyes on principles of differential reduction (*22*), but the possibilities along such lines are definitely limited. In general, dye mixtures can be analyzed by chemical means only after the separation of their individual components has been effected, and such separations are usually very laborious and frequently relatively ineffective. Spectrophotometric methods, on the other hand, are very convenient and have an extensive range of application.

The extinction coefficients of a mixture of dyes (when chemical action between such dyes is excluded) is the simple sum of those of its component dyes. When standard data have been obtained on the individual dyes in a mixture the analyst is equipped for the analysis of that mixture.

It is obvious that all standard data must be obtained with the same solvent and technic, and the dye mixture examined under precisely the same circumstances to obtain reliable results.

It has already been pointed out that water is unsuitable as a solvent in the analysis of dye mixtures, and a provisional technic has been outlined, employing 50 per cent alcohol, which is considered advisable. (P. 29.)

In obtaining data on individual dyes it is advisable to carry out measurements throughout the visible spectrum at intervals which are small enough to define the dye spectrum in detail. It is advantageous to adopt a standard dye concentration for such measurements or, at all events, to calculate the results to terms of a common dye concentration. Standard absorption curves can then be constructed on the basis of a standard concentration. These will be referred to as specific absorption curves. The utility of such specific curves is illustrated in Figure 10.

These curves illustrate the fact that there is a certain wave length at which the absorption of a mixture of two dyes is unaffected by variations in their relative proportions. At the point of intersection of specific absorption curves of dyes the only factor which influences the absorption of a mixture of those dyes is that of the total dye concentration (*24*).

In order to determine the total dye content of a mixture of two dyes, accordingly, it is only necessary to prepare a solution of appropriate concentration and determine its extinction coefficient at the wave length of intersection of specific curves of the component dyes. The ratio of the value obtained to the corresponding value on the

specific curves will be that of the concentration of total dye in the solution under examination to the standard concentration of dye employed in obtaining the specific data. The total dye content of the mixture may be calculated on that simple basis.

In some instances this single measurement may be all that the analyst may require. Nothing further is needed, for example, in determining whether mixtures of two food colors comply with the regulation of the Food and Drug Administration that they shall be labeled with a true statement of total dye content. More frequently, however, the analyst will also wish to determine the dye content of the individual components of the mixture. There are a variety of ways in which this may be accomplished.

When one of the components of a dye mixture absorbs light in a region of the spectrum in which the second component does not (at such dye concentrations as are employed in the examination of the mixture), it is obvious that its concentration may be determined directly by means of absorption measurements in that region. In the instance illustrated in Figure 10, for example, it would be possible to determine the concentration of dye B by means of measurements carried out at 610 mμ.

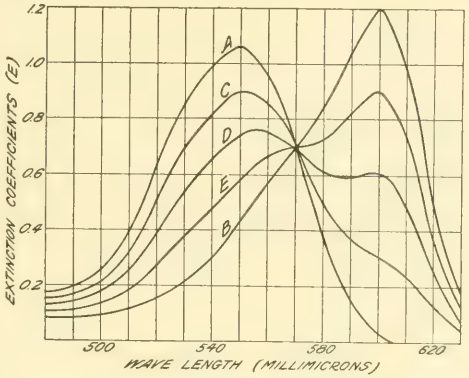

FIGURE 10.—Absorption spectra of two dyes and of mixtures of these dyes in which the total dye concentration is the same as that of the individual dye solutions: A, Dye A, 100 per cent; B, dye B, 100 per cent; C, 75 per cent dye A and 25 per cent dye B; D, 50 per cent each dyes A and B; E, 25 per cent dye A and 75 per cent dye B

Frequently, however, the analyst may find it necessary to depend upon measurements in regions in which the absorption of the dye components overlap. In such instances he may measure the extinction coefficient of the solution of his mixture at the maximum of one of its components. The value so obtained is reduced to specific conditions. In other words, he calculates what it would be if the total dye concentration of the solution under examination were the standard dye concentration employed in obtaining his specific data. (It is assumed, of course, that he has already determined the total dye concentration of his solution in the manner previously outlined and has, accordingly, the data necessary for the calculation in question.) The percentage of dye in the mixture may then be calculated by means of the formula

$$X = \frac{(a' - b)\,100}{a - b}$$

Where X = the percentage of dye A in the mixture.

a = the extinction coefficient of the specific curve of dye A at its maximum.

b = the extinction coefficient of the specific curve of dye B at the maximum of dye A.

a' = the extinction coefficient of the dye mixture solution at the maximum of dye A, reduced to specific value.

Referring again to Figure 10 it is assumed that a solution of a mixture of dyes A and B is found to have extinction coefficients of 0.56 and 0.72, respectively, at 570 mμ and 550 mμ. Then

$$a' = \frac{0.72 \times 0.70}{0.56} = 0.90$$

$$\text{and } X = \frac{(0.90 - 0.42)\ 100}{1.06 - 0.42} = 75 \text{ (per cent)}$$

Then 75 per cent of the dye mixture is dye A and 25 per cent dye B.

These values may be checked by means of further measurements at other wave lengths. In the absence of appreciable quantities of other dyes, it should be possible to obtain consistent results throughout the spectrum.

If the analyst prefers, he may establish the relative proportions of dyes in simple mixtures in a different manner. He may employ the ratio of extinction coefficients at, or near, the respective maxima of the dyes with which he is dealing. It will be evident that the value of this ratio will be unaffected by variation in total dye content but will be affected in a decided degree by any variation in the relative proportions of the components. Having specific curves of component dyes available, the analyst can calculate readily what values this ratio will have over the entire range of variation in percentage composition of mixtures of those dyes.

There is probably little choice between these two methods of determining percentage composition of mixtures in general practice. The analyst should make his selection between them on the basis of their relative advantages and disadvantages under the particular conditions with which he may be concerned.

These methods have certain practical limitations. They are of little value if one of the dyes is present in only very small proportion. Maximum accuracy is obtained only when the dyes involved have bands which are well separated in spectral location. They are very convenient to apply, however, and yield results, under favorable conditions, which are accurate within about 1 per cent.

With dye mixtures containing three components the proportion of instances in which accurate results may be obtained is smaller. When the forms of the specific curves are such as preclude reliable measurements of the concentration of any one or any two of the dyes, it becomes necessary to resort to complex calculations, and appreciable errors may result. Under favorable circumstances, however, it may be possible to obtain satisfactory results.

Having obtained standard specific absorption curves on three such dyes the analyst may evaluate a mixture of them by measuring E_1, E_2, and E_3 at $m\mu_1$, $m\mu_2$, and $m\mu_3$, where these wave lengths represent the maximum absorption of the dyes in question, A, B, and C, respectively.

Then it is obvious that—

$$E_1 = X_1 + Y_1 + Z_1$$
$$E_2 = X_2 + Y_2 + Z_2$$
$$E_3 = X_3 + Y_3 + Z_3$$

where X_1, X_2, and X_3 represent the extinction coefficients of dye A at $m\mu_1$, $m\mu_2$, and $m\mu_3$, and Y_1, Y_2, and Y_3 and Z_1, Z_2, and Z_3 represent

the extinction coefficients of dyes B and C, respectively, at the same respective wave lengths. Inasmuch as the ratios of the values of the extinction coefficients of each individual dye at $m\mu_1$, $m\mu_2$, and $m\mu_3$ may be calculated from the basic data previously obtained, and are constant under suitable working conditions, it is possible to solve these equations, obtaining values for X_1, X_2, X_3, Y_1, Y_2, Y_3, Z_1, Z_2, and Z_3. The percentage of the component dyes in the mixture may then be calculated by dividing these values by the specific extinction coefficients of the dyes at those wave lengths.

Applying this method in the evaluation of three mixtures of the dyes erythrosine, phloxine B, and rose Bengal B the authors obtained the results shown in Table 3.

TABLE 3.—*Percentage of the component dyes in mixtures of erythrosine, phloxine B, and rose Bengal B*

Dye mixture No.	Erythrosine		Phloxine B		Rose Bengal B	
	Present	Found	Present	Found	Present	Found
1	43.15	42.3	25.3	27.3	13.9	12.7
2	26.5	26.5	42.2	41.55	14.0	14.6
3	17.3	16.9	25.3	25.0	34.9	36.0

When independent measurements may be obtained upon one of their component dyes, mixtures of three dyes may be analyzed more simply and with greater accuracy. An example is given in Figure 11.

In evaluating such a mixture the concentration of dye C could be obtained directly by measuring extinction coefficients within the region between 575 mμ and 600 mμ. Further measurements within the region between 540 mμ and 560 mμ would give values for B and C from which the concentration of dye B could be obtained, since the values for dye C alone in the region could be calculated from the data already available. With the concentrations of dyes B and C established, it would be possible to make appropriate allowance for the absorption of those dyes in the region of shorter wave length, and obtain values for the concentration of dye A from absorption measurements therein.

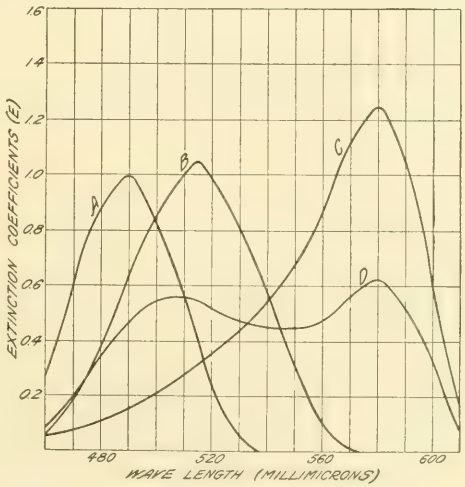

FIGURE 11.—Absorption spectra of aqueous solutions of three dyes and of a mixture of the same dyes: A, B, and C, Individual dyes; D, a mixture consisting of 20 per cent A, 30 per cent B, and 50 per cent C

Such methods as have been outlined hitherto for dye mixtures prove ineffective when the dye components differ but slightly in their hue and in the spectral locations of their absorption bands. This condition is seldom encountered in deliberate mixtures, but may frequently be met with in general practice. The analyst may wish to investigate the character of dyes which are commonly marketed as mixtures of varying proportions of similar individual components, or study the decomposition of dyes into products of similar color. In these, and in similar instances, the employment of absorption ratios may prove extremely useful.

Referring to Figure 9 it will be evident that if dye B contained as an impurity any appreciable proportion of dye A its absorption ratio would be increased, and that the increase would be proportionate to the percentage of dye A which was present. It can be calculated that it would require only approximately 3 per cent of dye A to raise the absorption ratio of dye B from 1.13 to 1.14. A careful determination of absorption ratios, accordingly, would enable the analyst to calculate the approximate percentage of dye A in mixtures of dyes A and B.

The accuracy of such determinations will vary considerably with conditions, depending in large measure upon visual sensitivity in the region in which the measurements are carried out and upon the spectral interval between the bands of the dyes in question. Under favorable conditions it is probable that results may be obtained which are accurate within about 2 per cent. In most instances, however, the method will prove decidedly less satisfactory. Even when conditions are such, however, that results obtained are only roughly quantitative, the method affords a very convenient means of obtaining information which is usually more definite than that obtainable by laborious chemical methods.

The absorption ratio method has been utilized in evaluating mixtures of methylene blue and trimethyl thionine (*30*), and in investigating the atmospheric dealkylation of methylene blue (*41*) and of cresyl blue (*36*).

SPECTROPHOTOMETRIC EVALUATION AND PRACTICAL DYE TESTING

The practical dye tester does not concern himself with absolute dye strengths. He adopts a convenient dye strength arbitrarily to serve as his standard, or type, and evaluates dye samples in terms of that standard, basing his estimate upon the results which he obtains in small-scale comparative dyeings. His operations are unquestionably more cumbersome and crude than are spectrophotometric or chemical methods of dye analysis. It might appear probable that the latter methods might advantageously replace those now in use for practical dye testing.

This possibility has been investigated at this laboratory and elsewhere, and the conclusions reached have been in substantial agreement. Spectrophotometric values can not be interpreted (as yet, at all events) in precise terms of brilliance and hue. Neither spectrophotometric evaluation nor chemical methods of dye analysis, moreover, can be relied upon to afford a reliable index of dye strength, with dyes in general, in the practical sense in which dye strength is judged in the industries. With some dyes analytical

results may agree closely with the dye tester's verdict, but with other dyes appreciable discrepancies may be encountered.

It is necessary to admit that analytical methods are not sufficiently developed, and that our knowledge of dyeing processes is not sufficiently complete, to enable one to define the essential dyeing properties of technical dyes from their analytical examination. Analytical methods, in short, can not replace practical dye testing.

INDICATOR METHODS

The application of spectrophotometric methods to indicator practice was made practically simultaneously by Holmes (*18*, *37*, *38*, *39*, *40*), by Brode (*3*), and by Thiel, Dassler, and Wulfken (*56*).

Indicators commonly change between two colors, although some indicators, like phenolphthalein, may exist in only one colored form. Certain indicators, such as the sulphonphthaleins, exist in three forms and have two useful transition ranges in color. A limited number of indicators exist in more than three forms.

Indicator changes are invariably accompanied by decided alterations in absorption spectra, and the degree of transformation of any indicator at any definite hydrogen-ion concentration within the range, or ranges, of its utility may be measured with the aid of the spectrophotometer and given numerical expression in terms of spectrophotometric ratios. The empirical calibration of such ratios against known hydrogen electrode values yields data which may be utilized subsequently in the determination of the Sörensen exponents of solutions of unknown hydrogen-ion concentrations.

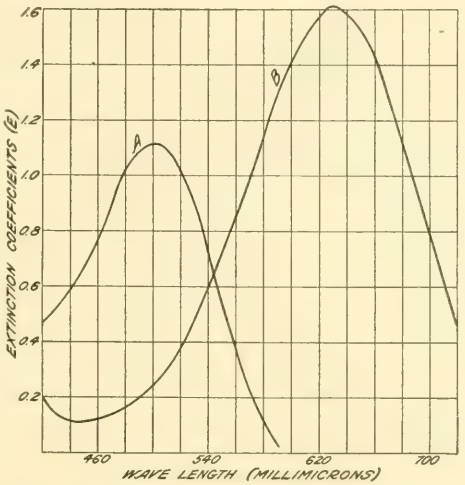

FIGURE 12.—Absorption spectra of aqueous solutions of 1-naphthol-2-sodium sulphonate indophenol at different hydrogen-ion concentrations: A, 75 mg per liter at pH 5.82; B, 37.5 mg per liter at pH 10.19

In point of fact the necessary spectrophotometric data for indicator practice can be calculated on theoretical assumptions. All that is required for the purpose is a knowledge of the apparent dissociation constant of the indicator and its absorption curves obtained under conditions which insure practically complete conversion, respectively, into its two color forms. The only assumptions required are that the indicator shall exhibit the essential behavior of a monobasic substance and that it shall conform to Beer's law. It is never entirely safe, however, to rely implicitly upon these assumptions, and an experimental verification of ratios is always advisable. Typical indicator transformations are illustrated in Figures 12, 13, and 14.

Within the region of its transition an indicator is essentially a mixture of two dyes, and the methods by which it may be investigated are those which have already been outlined for the analysis of dye mixtures. The courses which may be followed are illustrated by the graph of 1-naphthol-2-sodium sulphonate indophenol. (Fig. 12.)

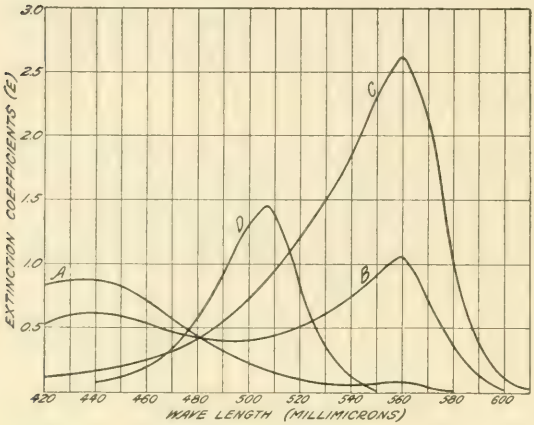

FIGURE 13.—Absorption spectra of aqueous solutions of phenolsulphonphthalein at different hydrogen-ion concentrations: A, At pH 6.3; B, at pH 7.5; C, at pH 10.2; D, in concentrated sulphuric acid

With increasing alkalinity, the indicator changes from a red form with maximum absorption at approximately 500 mμ to a blue form with maximum absorption at about 630 mμ. This transformation is practically complete in passing from pH 5.7 to pH 11.7, but 80 per cent of the alteration occurs between pH 7.7 and pH 9.7, and this smaller interval constitutes the useful working range of the indicator. Within the latter range any appreciable change in hydrogen-ion concentration is accompanied by a corresponding alteration in the relative proportions of the red and blue forms of the indicator and, consequently, by a corresponding alteration in the relative intensities of their absorption bands.

The degree of transformation of the dye at any given hydrogen-ion concentration in this range may be determined conveniently by means of absorption measurements carried out (1) at, or near, 630 mμ or (2) at, or near, 500 mμ, or (3) at both wave lengths.

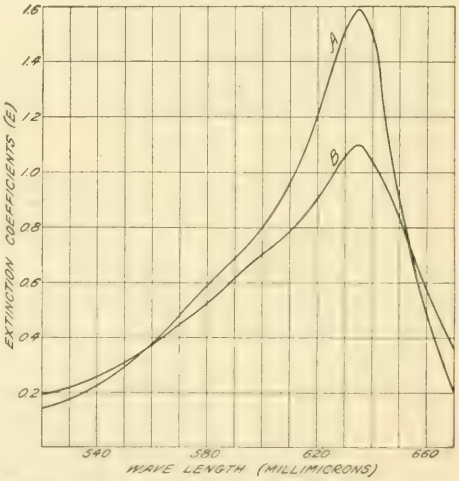

FIGURE 14.—Absorption spectra of aqueous solutions of fast green FCF at different hydrogen-ion concentrations: A, At pH 5.0; B, at pH 10.0

In the first instance, the blue form of the indicator would be measured alone, since the red form does not have appreciable absorption at that wave length in such concentrations as would be employed. The spectrophotometric ratio employed would be that of the extinction coefficient at 630 mμ under the conditions of the test to the extinction coefficient

at the same wave length of an equal quantity of indicator under conditions which insured practically complete conversion into the blue form. This type of ratio will be referred to by the term R_1. It will be evident that an R_1 ratio can be employed only with solutions in which the precise concentration of indicator is known.

In the second instance the red form of the indicator would be measured, primarily. In actual practice with this particular indicator, it is improbable that the analyst would employ an R_1 ratio at 500 mμ. Not only is the red form of the dye less intense than the blue form, but the alteration in extinction coefficients at 500 mμ per unit change in indicator transformation would be further reduced by the fact that the blue form of the indicator absorbs some light at that wave length, and that its absorption there would increase as that of the red form diminished. The analyst, accordingly, would prefer to measure the absorption of the blue form of the dye.

In the third instance the ratio employed would be that of the extinction coefficient of the solution under examination at 500 mμ to the extinction coefficient of the same solution at 630 mμ, or vice versa. This type of ratio, which will be termed an R_2 ratio, affords a maximum degree of alteration in value per unit change in indicator transformation, since both the increase in one absorption band and the simultaneous decrease in the other contribute to it. It will be evident that values of R_2 ratios will not be affected by changes in indicator concentration and that the R_2 ratios, accordingly, may be employed with solutions in which the concentration of indicator is not known.

In actual practice the analyst would probably prefer to employ some other wave lengths, for instance 520 and 600 mμ, rather than the wave lengths referred to in the previous discussion. The visual sensitivity of the analyst is appreciably greater at 520 mμ than at 500 mμ and at 600 than at 630 mμ. If such changes were made, the differentiating value of the ratios would decrease ostensibly, but it is probable that the actual accuracy of the methods would be distinctly improved, owing to the improved accuracy with which measurements could be carried out.

It is advisable, in general, to obtain both R_1 and R_2 values in calibrating spectrophotometric methods for use with indicators. Although R_2 values afford greater differentiation than do R_1 values, they do not necessarily afford greater accuracy. If the absorption bands of both color forms are in such spectral locations as will enable the analyst to obtain reliable measurements on both bands, R_2 values will prove preferable. If, however, the band of one color form is so situated that accurate measurements on it are difficult, as is the case with the sulphonphthaleins and many other indicators, it will usually be found that R_1 values prove distinctly more reliable.

Even in instances, however, in which the analyst may find that R_1 values prove somewhat more accurate than R_2 values, he may find the latter values very useful, and at times nearly indispensable. The fact that they are unaffected by variations in indicator concentration renders their use of great value in examining solutions of small volume or in other instances in which it may be difficult or impossible to insure a precise indicator concentration.

The accuracy of spectrophotometric methods with indicators is excellent. With certain samples of bromcresol green it was found

that their apparent dissociation constants (4.68, 4.65, and 4.69, respectively) could be checked so consistently in any extensive series of careful measurements that it was possible to distinguish between the samples in question with fair certainty (*18*, *37*, *38*, *39*, *40*). The methods may be relied upon to check electrometric methods nearly to the second decimal point in Sörensen (pH) units.

A table of solubilities of representative dyes at 26° C. in water and in 95 per cent alcohol is included for the benefit of any investigators who may have occasion to prepare dye solutions. (Table 4.)

TABLE 4.—*Dye solubilities at 26° C.*

[Data are expressed as grams of anhydrous dye per 100 cubic centimeters of saturated solution. Data in parentheses are expressed as grams of anhydrous dye per 100 grams of saturated solution]

Dye	Color Index No.	In water	In 95 per cent alcohol
Picric acid	7	1.18	8.96
Victoria yellow	8	1.66	1.18
Martius yellow (sodium salt)	9	4.57	.16
Martius yellow (calcium salt)		.05	1.90
Naphthol yellow S	10	8.96	.03
Aurantia	12	(1)	.33
Wool yellow G	16	18.40	.24
Chrysoidin Y	20	.86	2.21
Chrysoidin G	21	.23	.99
Sudan I	24	(1)	.37
Orange G	27	10.86	.22
Ponceau 2G	28	1.75	.21
Chromotrope 2R	29	19.30	.17
Alizarole yellow GW	36	25.84	.04
Alizarole orange G	40	.40	.57
Sudan II	73	(1)	.39
Azo Bordeaux	88	3.83	.19
Crystal ponceau	89	.80	.06
Erika B	130	.64	.17
Janus green	133	5.18	1.12
Metanil yellow	138	5.36	1.45
Methyl orange	142	.52	.08
Helianthin (color acid of methyl orange)		.015	.015
Orange IV	143	.16	.20
Azo acid yellow	146	2.17	.81
Resorcin yellow	148	.37	.19
Orange I	150	5.17	.64
Orange II	151	11.37	.15
Narceine	152	10.02	.06
Fast red A	176	1.67	.42
Amaranth	184	7.20	.01
Ponceau 6R	186	12.98	.01
Sudan III	248	(1)	.15
Brilliant croceine	252	5.04	.06
Erythrin X	254	6.41	.06
Sudan IV	258	(1)	.09
Biebrich scarlet	280		.05
Bismark brown Y	331	1.36	1.08
Bismark brown R	332	1.10	.98
Congo red	370		.19
Purpurin 4B	448		.13
Sky blue	520	13.51	(1)
Auramin O	655	.74	4.49
Victoria green (oxalate)	657	7.60	7.52
Victoria green 3B	659	.04	2.24
Guinea green B	666	(28.40)	7.30
Light green SFY	670	20.35	.82
Fast green FCF		16.04	.35
Pararosaniln (chloride)	676	.26	5.93
Pararosaniln (acetate)		4.15	13.63
Rosaniln (chloride)		.39	8.16
New fuchsin (chloride)	678	1.13	3.20
Methyl violet	680	2.93	(15.21)
Crystal violet (chloride)	681	1.681	3.87
Crystal violet (iodide)		.035	1.78
Anilin blue (spirit soluble)	689	(1)	1.10
Victoria blue 4R	690	3.23	20.49
Patent blue A	714	8.40	5.23
Cyanole extra	715	1.38	.44
New Victoria blue R	728	.54	3.98
Pyronin G	739	8.96	.60
Pyronin B (iodide)	741	.07	1.08
Rhodamin B	749	.78	1.47
Rhodamin G	750	1.34	6.31
Fluorescein (color acid)	766	.03	2.21
Fluorescein (sodium salt)		50.20	7.19
Fluorescein (magnesium salt)		4.51	.35
Fluorescein (calcium salt)		1.13	.41
Fluorescein (barium salt)		6.54	.56
Eosin (sodium salt)	768	44.20	2.18
Eosin (magnesium salt)		1.43	.28
Eosin (calcium salt)		.24	.09
Eosin (barium salt)		.18	.06
Ethyl eosine	770	.03	1.13
Eosin B	771	39.11	.75
Erythrosin (sodium salt)	773	11.10	1.87
Erythrosin (magnesium salt)		.38	.52
Erythrosin (calcium salt)		.15	.35
Erythrosin (barium salt)		.17	.04
Phloxin (sodium salt)	774	(50.90)	9.02
Phloxin (magnesium salt)		20.84	29.10
Phloxin (calcium salt)		3.57	.45
Phloxin (barium salt)		6.01	1.17
Rose Bengal (sodium salt)	779	36.25	7.53
Rose Bengal (magnesium salt)		.48	1.59
Rose Bengal (calcium salt)		.20	.07
Rose Bengal (barium salt)		.17	.05
Thioflavine T	815	2.11	3.17
Neutral red (chloride)	825	5.64	2.45
Neutral red (iodide)		.15	.16
Neutral violet	826	3.27	2.22
Safranin	841	5.45	3.41
Methylene violet 2RA	842	.69	3.18
Iris violet	847	3.12	3.66
Cresyl violet (NAC)		.38	.25
Nile blue 2B	914	.16	.62
Thionin	920	.25	.25
Methylene blue (chloride)	922	3.55	1.48
Methylene blue ($ZnCl_2$ double salt)		2.75	.05
Methylene blue (iodide)		.09	.13
Methylene green	924	1.46	.12
Toluidine blue O	925	3.82	.57
New methylene blue N	927	(13.32)	1.65
Alizarin	1027	(1)	.125
Alizarin WC	1034	7.69	.15
Indigo carmine	1180	1.68	.01

[1] Nil.

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UNITED STATES DEPARTMENT OF AGRICULTURE
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THE DEVELOPMENT OF PACKAGE-BEE COLONIES

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CONTENTS

	Page
Introduction	1
Previous data on development of package-bee colonies	3
Package-bee investigations at the bee-culture laboratory	6
General method of obtaining and working up data	6
Experiments in 1926	9
Experiments in 1927	12
Discussion of facts brought out in 1927 by package colonies as a whole	19
Weight of live bees in package on arrival in comparison with weight billed by shipper	19
Relation between number of bees in package as computed on basis of individual sample and basis of 5,000 bees to the pound	22
Importance of quantity of bees in package	25
Relation between size of package and rapidity of building up	25
Discussion of facts brought out in 1927 by package colonies as a whole—Continued.	
Actual length of time necessary for building up	29
Importance of bees of proper age	32
Length of time on road	33
Effect of weather conditions at time of installation	34
Use of sirup when installing packages	34
Effect of presence or absence of a queen bee in the package during shipment	35
Balling the queen bee	36
Importance of time when the queen bee is released	36
Importance of a prolific queen bee	37
Package bees as pollenizers	38
Package bees as honey gatherers	39
Summary	41
Literature cited	42

INTRODUCTION

The package bee has brought many new problems of apiary management to the beekeeper. To obtain more definite information on pertinent factors underlying these problems, particularly on the rate of development of packages of various sizes, work on package bees was undertaken in 1926 in the division of bee culture of the Bureau of Entomology. A knowledge of the rate of development of package colonies is of special importance to the beekeeper in many of his uses of the package bee if he is to choose the size of package which will best suit his purpose and if he is to know the proper time to obtain those packages.

Although in the United States bees have been shipped in combless packages for more than 40 years, only within the last 15 has the package-bee business assumed special importance. During these years it has increased by leaps and bounds. Recent statistics (*38*)[1] from the State of Alabama, which has become the center of the package-bee as well as of the queen-bee industry (*25*), well illustrate this

[1] Italic numbers in parentheses refer to Literature Cited, p. 42.

point. According to these statistics, in the two years from 1924 to 1926 the sales of package bees in Alabama more than doubled, 40,000 packages being sold in 1926 as against only 18,000 in 1924.

So far the commercial use of combless package colonies in honey production has been confined almost exclusively to the United States and Canada. It is only within recent years that the question of the practicability of combless packages under European conditions has been seriously raised in European bee journals. For a long time, however, there has been some traffic in colonies of bees between France and the British Isles, and also between the Netherlands and the British Isles. Within the last few years there has even been a beginning attempt to sell in the British Isles package bees produced in France. Russia, a country possessing vast extent and wide range of climatic conditions as well as immense beekeeping possibilities, seems to offer a big field for this phase of the beekeeping industry.[2]

In the past the production of package bees in North America has been practically limited to the United States, since Canada has depended for its supply on this country. The exact number of packages used in either country is not known, but Floyd (*9*) in 1929 estimated that, in Manitoba alone, 10,000 packages are needed to supply the annual demand.

Thus far the package-bee business has been confined largely to contiguous areas served by rail transportation. It has not figured in transoceanic shipments, no doubt partly because the conditions for successfully shipping bees in confinement for the long period necessary in such a case are not yet known. The importance of determining the proper conditions for shipping package bees successfully was one of the reasons for the establishment of the Southern States bee culture laboratory at Baton Rouge, La. Air transportation would appear the best means so far as the bees in the package are concerned, but resort to this method is not yet feasible.[3]

Package bees are bought, for the most part, for the purpose of building up new colonies in time for the honey flow, or of strengthening overwintered weak colonies so that they, too, may build up to sufficient strength to gather surplus. Recently Hutson (*14*) has advocated the procuring of packages in early spring for the purpose of having them build up to colonies strong enough for pollination work in orchards instead of relying on overwintered colonies.[4]

The results obtained in the last few years from the use of package bees to build up into new colonies for the honey flow, especially in some of the newer western and northern beekeeping regions, have often been surprising and may well explain the rapid development of

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[2] Since the foregoing was written, the use of package bees under conditions in the Union of Socialist Soviet Republics has become the subject of investigation there, one of the leaders in the movement being W. W. Alpatov, director of the biological laboratory at the zoological museum of the University of Moscow, who was a research fellow of the International Education Board at Johns Hopkins University in 1926-1928. As a matter of fact, as pointed out by the writer (*28a*) in a recent article, The Shipment of Package Bees in the U. S. A., which was translated into Russian by Alpatov and published in Kollektivnoe Pchelovodnoye Dolo for March, 1931, the Union of Socialist Soviet Republics seems the only country of beekeeping importance at present which embraces sufficient climatic range and contiguous territory for the development of a package-bee industry entirely within its own borders comparable to that now found in the United States. In The Bee Kingdom for July, 1931, A. Z. Abushady (*1*) reported the shipment of package bees from Jugoslavia to Egypt.

[3] Since the above was written advertisements offering for sale package bees shipped by air from France to England have appeared. (Cf. Scottish Beekeeper, April, 1931.)

[4] Since the original completion of the manuscript for this bulletin in 1929, Hutson (*15*) has described an "orchard package" to be used primarily for pollinating purposes. At this date (1931) several producers of package bees are advertising "orchard packages" for sale. The bees arriving in such packages are those depended upon to accomplish pollination, and they are permitted to fly directly from their original shipping container without being transferred to a hive.

this phase of the beekeeping industry. For instance, among some exceptional examples, it was reported (*36*) that 1-pound packages in Ontario in 1916 built up sufficiently to gather an average of 100 pounds of surplus honey in one season. In the sweetclover region of the North a 290-pound crop was reported (*16*) as the 1924 total from a 2-pound package installed in North Dakota on May 22 of that year. This particular region is marked by high colony yields because natural conditions make possible both exceptionally high daily gains and an exceedingly long period during which nectar is available. Sweetclover may bloom for about three months in North Dakota. A 3-pound package received in that State on June 5, 1922, was reported (*5*) to have gathered a honey crop of 485 pounds before the end of the same season.

It is not to be assumed from the foregoing examples that a direct relationship exists between the size of the package installed and the size of the honey crop obtained. Other factors which govern the total number of field bees on hand for the honey flow enter in as well. Among these are the relative rapidity with which packages of various sizes build up, the length of time between the receipt of the bees and beginning of the main honey flow, the age of the bees when put into the package, the queen bee herself, and whether the worker bees in the original package prove of field use in the main honey flow if obtained late enough or whether their energy is all expended in rearing brood to replace themselves. The division of labor in the honeybee is also a governing factor since, as summarized by the writer on another occasion (*26*), it has long been common knowledge that under normal conditions the worker honeybee spends the forepart of its life in various activities which it has been the custom to group under the heading of hive duties, while the latter part of its life is devoted to field duties such as gathering nectar, pollen, water, and propolis. On the other hand, when compelled to do so, bees may go to the field earlier than they would normally, or to a limited extent old bees may perform hive duties.

Recent research by Rösch (*37*) has placed our knowledge of the division of labor on a more scientific basis than heretofore and has brought out new facts as well. The work of Soudek (*39*) on the glands of the worker honeybee is also an important contribution toward the solution of this problem.

PREVIOUS DATA ON DEVELOPMENT OF PACKAGE-BEE COLONIES

Few data from any direct study of the factors governing the development of package colonies have been published. Most of our ideas on the subject have been obtained incidentally from casual observations made by beekeepers while using package bees in their apiaries. From the scientific side the most comprehensive work on the problem published thus far is by Merrill (*19*), who presented data showing the average population and amount of brood at intervals varying from 22 to 24 days throughout the season of 1923 in four colonies started from packages on April 30 of that year. The population was apparently determined each time by taking the weight of the bees in pounds and then multiplying this by 5,000, the commonly accepted number (*34, p. 760*) of bees in a pound. Merrill (*22*) later published some other results obtained with package bees, but these seem to represent abnormal conditions and need not be discussed here.

There might be objection to deriving population from weights by using some constant conversion factor like 5,000 bees per pound instead of the average weight of a representative sample of bees obtained at each weighing of the whole colony. Such an objection is not invalid when it is remembered that the average weight of an individual bee varies, depending on the load carried in its honey sac. Furthermore, since Alpatov and Tjunin (*2, pp. 2–7; 3, p. 99*) have found the body dimensions of the honeybee to vary somewhat with the colony, and since Mikhailoff (*23, 24*) states that these dimensions vary even in the same colony at different times of the year, it is only reasonable to suppose that weight may possibly do likewise.

If Merrill's brood counts had included only brood, all or most of which eventually developed into the adult stage, the number of bees which should have been on hand at any time during the active season under any given average length of life for the bees at this period of the year could easily be computed from these counts, and a fair check on his numbers derived by weight could be obtained. Thus, since only 21 days are required for development from egg to adult, if brood counts are taken every 21 days and, in addition, if the average length of life of the worker bee during the active season is assumed to be six weeks or more, as has been assumed by some writers, such as Pellett (*31, p. 93*), Phillips (*33, p. 136*), the Roots (*34, p. 17*), and Zander (*41, p. 74*), it follows that the total population at the time of any particular brood count would be equivalent to at least the sum of the brood counts on the two preceding dates, provided all the brood develops. If the average life of the worker during the active season is assumed to be about five weeks, the period assumed by other authorities, such as Buttel-Reepen (*4, p. 133*), Dadant (*17, p. 64*), Leuenberger (*18, p. 7*), and Rösch (*37, p. 628*), the total population on any of these dates should be the total brood count on the preceding date plus approximately two-thirds of the total brood count on the second preceding date. The exact fraction to be used in this case depends on the weekly emergence of the brood included in this count.

The use of counts of total brood in computing population, however, may introduce a considerable error in the result, since it is known that not all eggs or unsealed larvæ reach the adult or even the sealed stage. Merrill has published data (*21*), for the same year as his experiments with package colonies, which indicate that sometimes as much as one-third of the unsealed brood in certain colonies investigated did not reach the sealed stage.

Merrill received his packages on April 30, and from his calculations each contained, on an average, 14,000 bees. He states that in his locality the main honey flow for that year (*19*) occurred between June 18 and July 11, but that during the last of August and the first week of September there was another honey flow.

His first determination of brood and population was made on May 26, 26 days after the packages had been received. Since worker bees require an average of 21 days to develop from egg to adult, any bees on hand at this time either survived from the original packages or else had emerged between May 21 and May 26. It does not seem likely that an average of much more than 3,000 bees had emerged in each colony by May 26, since the total number of cells of brood found then, 13,000 cells, indicates a daily egg-laying rate, or a subsequent daily emergence rate, of only 619. Merrill's data show

an average of 10,200 bees in each package colony, a large number of which, therefore, must have survived from the original number received.

The second determination was made on June 18, seven weeks after the packages were received. It may be assumed that practically all the bees from the original packages were dead at this time, whereas all of the worker brood, 13,000 cells, found on May 26 would have had time to emerge and would still be alive, together with whatever bees had emerged as a result of brood-rearing activity before the 21-day period covered by this brood count. As a matter of fact Merrill reports, for June 18, 13,250 bees and 11,000 cells of brood. The sealed brood count represents a daily egg-laying average of only about 500. This decrease in the amount of brood will be commented upon later.

The next reading, on July 11, about 10 weeks after installing the packages, showed 18,000 bees. This is approximately 1.3 times the number computed as in the packages on arrival. The number of cells of brood had increased to 15,200, which means an increase in the egg-laying rate. For the reading three weeks later, August 2, about 13 weeks after the packages were installed, Merrill gives the population as 22,000 and the brood as 17,800 cells. He continued his counts on these colonies throughout the season, but the later counts seem of less value in a study of colony development.

After the decrease shown by the second brood count, the computed daily egg-laying average rose until the maximum, approximately 1,000, was attained, about 16 weeks after the packages were received. That these colonies were laboring under a handicap throughout the season might seem evident from the fact that Merrill (*20*) states elsewhere, in reporting on other colonies in the same apiary in the same year, that the highest daily rate of egg laying in any colony was 2,030 and that this occurred during the nine days previous to June 21. It fell to 1,400 during the next nine days. This highest rate occurred during the period covered by the second count for the package colonies, the interval in which the egg-laying rates of their queens were dropping off. The average given in the same article (*20*) for certain of his colonies in August of that year is a little more than half that of the same colonies for June.

The decrease in brood rearing found by Merrill between May 26 and June 18 is significant of what was taking place in colony population, especially since he (*20*) reports that this was the period of greatest brood-rearing activity in other colonies in the same year. As stated before, on May 26 the population was composed largely of package bees. Toward the end of May these bees must have aged physiologically to the point (Rösch, *37, p. 627;* Soudek, *39, p. 57*) at which their efficiency as nurse bees was becoming impaired. After May 26 these old bees must have died even more rapidly than new bees emerged because they had now been working practically four weeks, to say nothing of their age when put into the packages. With the sudden rapid decrease in field bees, bees normally of hive age would be called upon to go to the field. Consequently, both field and hive activities would seem to have suffered somewhat at this time. Following June 18, the course of brood rearing is clearly upwards.

In studying Merrill's data, it is apparent that by June 18, the beginning of the main honey flow and seven weeks after the packages were installed, brood rearing in these colonies had been only suffi-

ciently active to result in enough new bees to equal approximately the number in the packages originally. It is to be assumed that practically all of the bees contained in the packages were dead at this time. Furthermore, according to Merrill's data the colony population at no time during the season was double that originally in the packages.

It is rather difficult to associate the slow development of these packages and their low maximum population for the season with the astounding performances by packages in other localities mentioned earlier in this bulletin. It may be well to bear in mind that Merrill's data are based on averages from four packages, and that the data from his best package might indicate a much greater possible rapidity of increase in population. Moreover, no information is given as to the apparent age or condition of the bees on arrival, nor whether they were shipped and installed in inclement weather.

Few scientific data obtained by other investigators of the development of package colonies are available, although Wilson (*40*), in 1920, endeavored to obtain data on the relative merits of 2 and 3 pound packages. His experiment, however, was interfered with by cold weather during the time of shipping some of the packages. Other packages, whose size he does not state, but which were received by him on May 1, built up so strongly by July 1, a little more than eight weeks, that he says it was impossible to prevent their swarming. Because of this he holds that packages should not be received too early, at least in Wisconsin.

Farrar (*10*) in 1927 published some observations on package colonies in North Dakota. The highest effective daily egg-laying average given in his data is only 900, and was first attained about six and one-half weeks after the package was installed. This is derived from sealed-brood counts. He also reports that the package was storing surplus honey on the sixth day after being installed. He further states that not all the original package bees were dead 10 weeks after installing the package.

PACKAGE-BEE INVESTIGATIONS AT THE BEE-CULTURE LABORATORY

It was in view of the scantiness of information on the development of package colonies that the investigation in this field was begun in 1926 at the bee-culture laboratory of the Bureau of Entomology at Somerset, Md. During this year the development of a package colony founded from a single package, of a package colony formed by uniting three packages, and of an overwintered colony reinforced by a package, were studied. Even this meager work, however, gave certain leads which showed the advisability of further investigations, and so in 1927 the experiment was continued on a much larger scale.

GENERAL METHOD OF OBTAINING AND WORKING UP DATA

At the present time a package of bees is obtained more for the purpose of starting a new colony or of strengthening a weakened one than for any honey which may be stored by the bees in the package, or for its direct use in pollination. Under these conditions its value to the beekeeper, other things being equal, may be gaged by the rate at which it builds up; in other words, the rate of addition of new bees. Inasmuch as sealed brood represents the last stage before the emergence of the adult bees and under normal conditions practically all

will emerge, the rate at which new bees will be added to the colony throughout the season can be more accurately determined by computations based on sealed-brood counts made at least every 12 days than by any other method, except counting the bees as they emerge. For the package-bee investigation, therefore, counts of sealed brood made by photographic means, as described elsewhere (*28*, *pp. 4–6*), were used.

The daily rate of sealing worker brood, for purposes of calculation, may be assumed to be equivalent to the rate of emergence 12 days later, or to the effective egg-laying rate (*27*) nine days earlier. It will be well to describe the method by which the average daily rates of sealing were worked out by the writer for the data discussed here.

If it is assumed that worker brood remains sealed for an average of 12 days, any single count of the sealed brood in a hive will cover all the brood sealed during a 12-day period ending at the time of the count. It is quite obvious, therefore, that in case of two successive brood counts made less than 12 days apart, the brood sealed during the latter part of the 12-day period represented by the first count will be included in the total for the second count. In other words, the 12-day period represented by the second count will overlap that represented by the first, the number of days included in the overlapped interval being dependent upon the length of time between the counts. It follows, therefore, that the mathematical difference between two successive counts of sealed brood at any interval of less than 12 days is the difference between the amount of brood sealed in that portion of the 12-day period covered by the first count which is not included in the overlapped interval, and the amount sealed in that portion of the 12-day period covered by the second count which is likewise not included in the overlapped interval.

Take, for instance, two successive counts made on May 12 and 19, respectively. The first count covers all brood sealed from May 1 to 12, inclusive; the second count includes all brood sealed from May 8 to May 19, inclusive, while the overlapped interval, or period covered by both counts, extends from May 8 to May 12, inclusive. The portion of the two counts sealed during these five overlapped days is obviously identical, while the difference between the two counts, if any, represents the difference between the brood sealed from May 13 to 19, inclusive, and that from May 1 to 7, inclusive. If the count on May 19 is larger than that on May 12, the difference between the two will be the difference by which the number of cells sealed from May 13 to 19, inclusive, exceeds the number sealed from May 1 to 7, inclusive. On the other hand, if the count on May 19 is less than that on May 12, this represents the difference by which the number of cells sealed from May 13 to 19, inclusive, is less than the number sealed from May 1 to 7, inclusive.

If under the conditions of the foregoing paragraph a third count is assumed to have been made on May 26, the brood sealed from May 20 to 26, the nonoverlapped portion of the second count, would be equal to the brood sealed in the nonoverlapped portion of the count on May 19 plus or minus the difference between the amount of brood found on May 26 and that on May 19. In this particular case the nonoverlapped portion of each count is seven days. The nonoverlapped portion of the count of May 19 is therefore the period from May 8 to 14. This period includes five days sealing (May 8 to 12, inclusive), at the rate for May 1 to 12, as mentioned in the preceding

paragraph, plus two days sealing (May 13 and 14), at the rate for May 13 to 19, as also computed there.

With the foregoing as a basis it is comparatively easy to compute the course of the daily rate of sealing (daily effective egg-laying rate 9 days earlier) from a series of successive sealed-brood counts throughout the active season taken at intervals of less than 12 days. It is necessary only to obtain the differences between successive counts and then in succession to add them to or subtract them from, as the case may be, the total for the corresponding nonoverlapped interval. The daily total for the 12-day period represented by the first of a series of successive counts at intervals of less than 12 days is obtained by assuming a uniform rate of sealing during the 12 days covered by the first count, unless the count was taken less than 12 days after the sealing began. In other words, the daily sealing rate during this period is assumed to be one-twelfth of the total for the 12-day period, or the corresponding fraction if less than 12 days is involved. In ordinary cases the first reading of the year in sealed brood will be so small, if taken in time, as to make little difference whether the exact day on which sealing began is known or not. In the example given in the preceding paragraph, therefore, the daily rate of sealing from May 1 to May 12, inclusive, would be taken as one-twelfth of the total sealed brood found on May 12, while the total sealed brood during the seven days from May 1 to 7, inclusive, would be seven times this daily rate. The brood sealed from May 13 to 19, inclusive, therefore, would be equal to the computed amount of brood sealed from May 1 to 7, inclusive, plus or minus the difference between the counts on May 12 and 19, depending on whether the first count is less or greater than the second.

Having worked out the rate of emergence of any colony throughout the season, it is a simple matter to work out the total colony population and the approximate composition in hive bees and field bees at certain dates. In doing the latter, results obtained by Rösch (*37, pp. 627–628*) may well be followed, because his is the most complete attempt to determine the average age at which worker bees take up successive duties in the colony.

Assuming a 35-day period of life for the worker bee, according to Rösch the first 19 days are devoted to hive duties and the last 16 to field duties. Rösch holds further that the first 2 days of the worker's life are given over to cleaning out cells for egg laying; the next 8 to nursing young bees; the next 9 to intermediate hive duties such as relieving incoming field bees of their loads of nectar, carrying out débris, guarding, and the like; while the last 16 are devoted to field duties. Even under normal conditions it is not to be expected, however, that these time divisions are always hard and fast.

The only objection to Rösch's data is that he worked on an observation colony and consequently his bees, through being unduly active, may have been more short-lived that those in colonies under apiary conditions. However, for the purpose of this bulletin it will be better to use too low a figure rather than one too high. Soudek's results, moreover, are quite in accord with those of Rösch as to the nursing period, on the basis of the anatomical and physiological development of the pharyngeal glands of the worker bee. Recent work by Perepelova (*32, p. 557*) in Russia has borne out Rösch in other respects.

In all of the computations of colony population for successive weeks in this bulletin, bees which arrived with the package are disregarded. The computations are based on the number of bees reared after the packages had been installed and assumed to be still alive at the end of the various weekly periods.

EXPERIMENTS IN 1926

Although in 1926 only one of the packages investigated (No. 301) was allowed to build up independently, its development was quite equal to any of those investigated in the succeeding year and would at least seem to be equal if not superior to the minimum which might be expected under optimum conditions. The total weight of the bees in this package was 2½ pounds when received by express from a southern producer on April 23, 1926. It was hived on drawn combs on the day of arrival, having been on the road two days. The package already contained an introduced queen bee, but this queen was accidentally lost on June 16. The record of its sealed brood and the computed emergence for this colony are contained in Table 1.

TABLE 1.—*Record of sealed brood and computed emergence of workers in package colony No. 301*

Sealed-brood counts			Computed emergence of workers		
Date	Worker	Drone	Days after installing package on Apr. 23	Emergence of workers	Average daily emergence
May 7 [1]	6,859	12	22–26	6,859	1,371.8
May 12	14,079	35	27–31	7,220	1,444.0
May 18	15,751	74	32–37	7,159	1,193.2
May 25	15,268	99	38–44	9,302	1,328.9
May 29	15,963	189	45–48	5,468	1,367.0
June 8	16,587	284	49–58	13,853	1,385.3
June 16	16,441	257	59–66	10,899	1,362.4
June 21	16,745	146	67–71	7,208	1,441.6

[1] May 3 marks first sealed worker brood.

The main honey flow at Somerset was on in force three weeks after the package was received, and was over before the end of May. Its source was the tuliptree (*Liriodendron tulipifera*). Black locust (*Robinia pseudo-acacia*) also yielded abundantly just before and during the beginning of the tuliptree nectar flow. June was marked by nectar flows from both white clover (*Trifolium repens*) and white sweetclover (*Melilotus alba*), and exceptionally from basswood. These nectar flows were at least sufficient for stimulating brood rearing.

Of the other two colonies used in 1926, No. 201 was started on March 25 by hiving on drawn combs a 3-pound queenless package shipped from the South. Two more 3-pound packages were added to this new colony on April 1. The total live weight of the bees in the three packages, however, due in part to the mortality in two of the packages while being shipped, was not over 8½ pounds. Table 2 gives data on the brood counts and emergence of workers in this colony.

TABLE 2.—*Record of sealed brood and computed emergence of workers in package colony No. 201*

Sealed-brood counts			Computed emergence of workers		
Date	Worker	Drone	Days after installing last 2 packages	Emergence of workers	Average daily emergence
Apr. 19 [1]	6,819		26–30	6,819	1,363.8
Apr. 24	11,865	36	31–35	5,046	1,009.2
Apr. 30	13,692	350	36–41	7,282	1,213.7
May 7	15,317	656	42–48	9,249	1,321.3
May 12	16,394	399	49–53	7,145	1,429.0
May 18	15,625	147	54–59	7,159	1,193.2
May 24	15,289	390	60–65	8,130	1,355.0
May 29	15,557	493	66–70	6,234	1,246.8
June 8	14,924	168	71–80	12,431	1,243.1
June 14	14,481	180	81–86	7,023	1,170.5
June 21	12,369	263	87–93	6,517	931.0

[1] Apr. 15 marks first sealed worker brood.

Colony No. 302 had been wintered in the apiary, and was reinforced on March 25 by a 3-pound queenless package shipped from the South. Before the package was added to it, the colony contained 3.3 pounds of bees. Table 3 gives the records of sealed-brood counts and the computed emergence of workers in this colony.

TABLE 3.—*Record of sealed brood and computed emergence of workers in package colony No. 302*

Sealed-brood counts			Computed emergence of workers		
Date	Worker	Drone	Days after installing package	Emergence	Average daily emergence
Apr. 12 [1]	4,522	123	26–30	4,522	904.4
Apr. 19	12,749	476	31–37	8,227	1,175.3
Apr. 24	14,829	431	38–42	6,602	1,320.4
Apr. 30	16,177	419	43–48	8,400	1,400.0
May 7	16,945	591	49–55	9,945	1,420.7
May 12	17,459	383	56–60	7,514	1,502.8
May 18	18,780	189	61–66	9,845	1,640.8
May 25	17,506	394	67–73	9,302	1,328.9
June 2	16,721	492	74–81	11,406	1,425.8
June 9	15,392	978	82–88	8,264	1,180.6

[1] Apr. 8 marks first sealed worker brood.

Fewer than 600 sealed drone cells were found in any of the three colonies at any one time, except on May 7 when 656 drone cells were found in No. 201, and on June 9 when 978 sealed drone cells occurred in No. 302. The highest number in No. 301 was 284.

The first new worker bees in each of the three colonies emerged during the fourth week after the packages were installed, but for several reasons the number emerging in Nos. 201 and 302 (Table 4) was smaller, according to the calculations, than that in No. 301. In the first place their queen bees did not come with the packages, and to insure their safety they were so caged that the workers did not release them until four days after the packages were hived, whereas in No. 301 the queen was already free among the bees in the package on arrival. Furthermore, in No. 301 brood rearing began in one of the periods of the year most conducive to egg laying in the apiary at Somerset,

owing to the abundance of fresh nectar and pollen available, and this fact alone should have caused brood-rearing activity to be more intense at that time than in No. 302 at least, provided the queen bee was in good condition and had sufficient bees and room.

TABLE 4.—*Computed population in successive weeks of worker bees reared after installation of packages used in 1926*

Colony No.	Worker population at end of specified number of weeks								
	4	5	6	7	8	9	10	11	12
201	4,091	11,865	20,468	29,825	39,120	44,029	45,199	45,298	44,352
301	9,747	18,852	27,882	37,393	47,090	46,926	47,674		
302	2,713	10,398	19,351	29,172	39,199	47,420	49,972	50,709	50,133

In colony No. 201 the queen was caged twice, the first time March 25, when the first package was installed, until her release on March 29. Three days later she was again caged, because the two additional packages of bees were installed at that time. By April 5, or four days later, she had again been released by her bees. The first sealing of brood from eggs laid after the queen's second release occurred on April 15, or 14 days after the second lot of bees had been united with the first. A few cells of brood resulting from the activity of the queen during her first release have been disregarded in the computations.

In colony No. 302 the first sealing of brood from eggs laid after the package had been united with the original colony occurred on April 8, which was likewise 14 days after the package was installed. In colony No. 301, on the other hand, the first brood was sealed on May 3, or only 10 days after the package was received.

Although the queen in No. 301 started egg laying four days sooner after installation of the package than did the queens in Nos. 201 and 302, their rates of increase until the end of the eighth week are quite similar (fig. 1), notwithstanding the fact that No. 301 was installed three weeks later than the last packages in No. 201, and four weeks later than the package in No. 302. Colony 301 showed little change in population in the eighth and ninth weeks, and, unfortunately, became queenless at such a time that its full performance during the eleventh week could not be calculated. Colonies 201 and 302 made gains in population in the ninth and tenth weeks, but in each case the computed population in the eleventh week shows little increase over that in the tenth. The figures for the twelfth week show a decline.

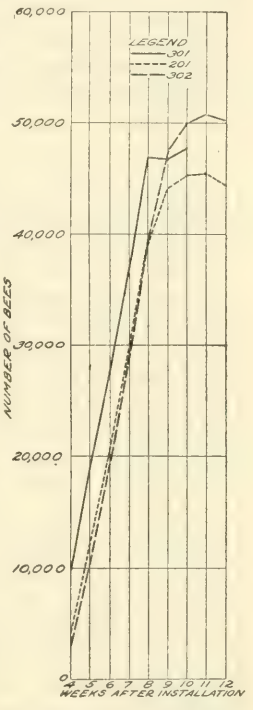

FIGURE 1.—Computed worker populations for successive weeks after installing package colonies used in 1926

Comparative numerical data as to the number of bees on hand in each colony at the beginning of the experiment are not available, but, on the basis of the population computations, Nos. 302 and 201

each had 39,000 bees at the end of the eighth week, while No. 301 had slightly more than 47,000. Two weeks later, however, No. 302 had practically reached the 50,000 mark, No. 201 was at 45,000, while No. 301 was still at about the level of the eighth week. The figures for the tenth week represent about the maximum for all three colonies, although Nos. 201 and 302 made minor gains during the next week.

EXPERIMENTS IN 1927

In 1927 the work was continued on a much larger scale, 40 packages being used. These, plus 10 additional packages, were received from the south by express in lots of five. With three exceptions the individual lots arrived at intervals of one week over a period of 10 weeks beginning March 16. The exceptions were lots 3 and 5, which were received one day behind their schedule, and lot 6, which arrived one day early. Each shipment consisted of a 1-pound, a 2-pound, a 3-pound, a 4-pound, and a 5-pound package. They were all on the road from two to three days. Sugar sirup from an inverted tin can fastened in the top of the cage provided food on the journey in addition to any honey the bees may have had in their honey sacs when shaken into the cages. A cloth wick extending through a small hole punched in the can enabled the bees to get at the sirup.

SOURCE OF THE BEES

The packages were all furnished by the same producer to insure uniformity in stock and in age so far as any particular breeder emphasizes these points. If they had been ordered from several different shippers, there would have been the risk of receiving packages put up under widely different conditions both as regards age of the bees and other factors. The producer from whom the bees were ordered was not informed of the purpose for which they were being purchased. Thus, in putting them up he had no occasion for using care other than that taken regularly.

All the queen bees used in this experiment were introduced after the packages had been installed in the hives. In no case did a package arrive with a queen bee already introduced into it. In nearly every case the queen bee was in a mailing cage suspended by fine wire inside the package. In some instances these mailing cages were nailed to the outside of the shipping cage. The queen bees used for the first three lots, however, were obtained from a producer other than the one furnishing the bees, so that these lots were shipped altogether queenless, while the queens came by mail. The queen bees for the last two lots also came by mail, while the packages were shipped queenless by express.

HANDLING THE PACKAGE

Before a shipment was received a hive was prepared for each package. A 10-frame hive body filled with empty drawn combs was used in each case and above this hive body an empty half-depth super was placed, and then the inner cover and the outer cover. The entrance was closed down to a bee space when the package was hived, and later was opened wider when necessary. A Boardman feeder block with a 2-quart glass can was provided at the rear of each hive. The feeder block was shoved through an opening cut in the bottom board.

Each of the shipping cages had two holes in its cover, one being stopped by the food can and its tin flange and the other by a thin piece of wood. When the package was installed, the food can and the piece of wood were removed from the container, thus providing ample exits. The cage was then placed on its side within the half-depth super, resting immediately upon the top bars of the frames. No special attempt was made to get the bees out of the package at this time, but in most cases they were all out by the following morning. The shipping cages and the half-depth supers were then removed, after shaking out any bees which might still be lingering in the shipping cages. This method of installing the packages proved highly convenient during the experiment, since the cages were emptied of bees and were later removed with scarcely any disturbance being caused to the bees themselves. All the lots were received at the bee-culture laboratory in the afternoon, and, with the exception of lot 10, were installed on the day of receipt.

In each hive a Miller introducing cage containing a queen bee was suspended between two of the combs by a bent nail, before the package was installed. The queen bee was placed in this cage without attendants, the exit hole being stopped solidly with candy. In the first lots the queen was caged "safely" by tacking a narrow tin strip across the candy on the outside of the cage, as described by E. R. Root (*35*) in 1908. In such instances the tin was removed the next day, giving the workers a chance to eat out the candy. Whether the tin was used or not, the candy was eaten and the queen freed usually within 24 hours to 36 hours after the workers had access to the candy. Sometimes in cool weather, before the cage with its queen bee was hung between the frames, it was thrust into the package cage for a minute or so until a handful of bees clustered on it.

In order to determine the number of drones in the various packages, excluders were placed between the hive bodies and the half-depth supers used in preparing the hives for all the lots except the first two. The workers, of course, quite readily passed through the excluder to the comb below, where the queen was already caged, while any drones were trapped above in the half-depth super. In most cases they were clustered the next morning. The highest number found in any package did not exceed 75.

Since the main purpose of this experiment was to see how rapidly packages of various sizes build up, and since packages were received over a period of 10 weeks, during which time any nectar flow would normally be subject to variation, feeding was resorted to continuously for all packages to insure that each was under the same conditions as to abundance of food supplies at all times. It is to be remembered that the packages were installed on drawn combs, all of which were empty except for a cupful of the sirup poured into one of them just before installation. The queen in her cage was placed next to this sirup.

The sirup given consisted of 5 parts of sugar to 3 of water. This, of course, approaches a winter sirup rather than one for stimulative feeding. The object in using sirup of this thickness was to reduce the activity of the bees in driving off the excess water. The relative quantities of sirup used per day by the various colonies could readily

be gaged by measuring in inches how much the level of the sirup in each can was lowered. These were replenished as soon as empty.

In all lots the net weight of living bees on hand was determined for each package on arrival. A sample, usually of 50 to 100 workers, was then taken from each package in each lot except the first, and the average weight of the individuals in the sample was determined. This was used as the average weight of individuals in the whole package in computing their total number from the weight of live bees in the package. These data will be presented in tables and will be discussed later.

The last numeral in the numbers designating the various colonies used in 1927 denotes the size of the packages in pounds as billed by the producer. Thus No. 402 represents a 2-pound package, while No. 424 represents a 4-pound package.

It should be noted further that lot No. 1 includes package colonies Nos. 401 to 405, lot No. 2, colonies Nos. 411 to 415, and so on through the series to lot No. 10 which includes colonies Nos. 491 to 495.

FLORAL AND WEATHER CONDITIONS

Ordinarily in the vicinity of Somerset, Md., pollen from the field becomes available as early as March in sufficient quantities to supply normal brood-rearing requirements. This held true in 1927, and all the package bees had an abundant pollen supply from the time they were hived, with the possible exception in some instances of a few days of cool or rainy weather. A sufficient supply of sirup or honey and of pollen was, therefore, available practically at all times. The main nectar flow, that from the tuliptree, was on in full force by May 17 and lasted until the first week in June. Some nectar was available from sweetclover in the remainder of June.

In spite of any endeavor to secure bees of a uniform stock and age, or to provide an abundance of food, weather conditions remain a variable factor. During this particular experiment it was unseasonably cold on seven of the last nine days in March; during two 5-day intervals, one 4-day interval, and one 3-day interval in April; and for a 7-day interval in the middle of May. (Fig. 2.) From the day after the beginning of the experiment, March 17, until April 5 the maximum temperature ranged below 55° F. except on March 30 and 31, when the temperature reached 56° and 62°, respectively. On April 6 it reached 68°, but on the morning of April 9 the ground was white with snow. On April 12 the temperature reached 74° during the day. At that time apple trees were in bloom, and much pollen was carried in. On April 17 a scale colony registered a gain of 1 kilogram. The last nine days in April were cool, the temperature being 46° or lower every morning except one when it was 50°. May saw much warmer weather, although from the 12th to the 18th the temperature ranged between 45° and 53° in the morning. By obtaining the bees over a period of weeks, however, instead of all at once, there was less chance of having the whole experiment too seriously affected by any adverse weather, and a better opportunity was given to study the time of arrival of the package in relation to the main honey flow.

BROOD REARING OF THE PACKAGE COLONIES

A complete history of each individual colony used in 1927, with particular reference to its brood rearing, would involve much repetition of detail which often varies little from colony to colony. Consequently the colonies will only be discussed collectively in connection with the general facts brought out by the experiment as a whole. The reader will be able, however, to trace readily the brood-rearing record of any individual colony from the data on sealed brood con-

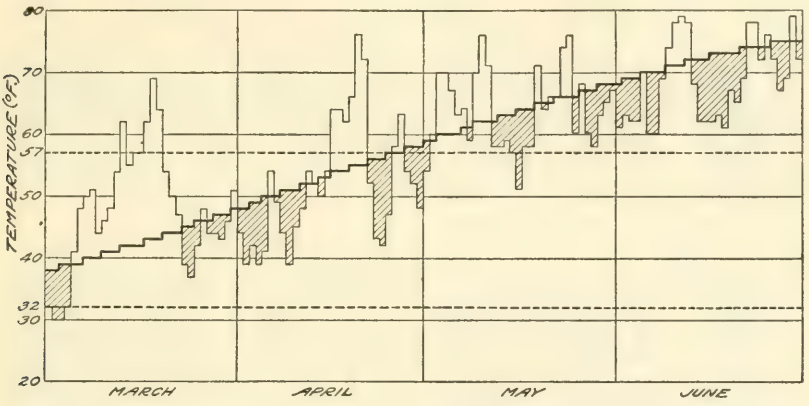

FIGURE 2.—Departure of mean daily temperature from normal mean from March to June, 1927, inclusive. Heavy line represents normal mean temperature, with mean daily departure above it shown by unshaded graph and mean daily departure below it by shaded graph. (Data taken from Monthly Meteorological Summary for Washington, D. C., published by the Weather Bureau, U. S. Department of Agriculture, for the month in question)

tained in Table 5. The emergence rates computed for various successive periods are also included in that table.

TABLE 5.—*Record of sealed brood and computed emergence of workers in package colonies at Somerset, Md., 1927*

COLONY NO. 401						COLONY NO. 402					
Sealed-brood counts			Computed emergence of workers			Sealed-brood counts			Computed emergence of workers		
Date	Worker	Drone	Days after installing package	Emergence	Average daily emergence	Date	Worker	Drone	Days after installing package	Emergence	Average daily emergence
Mar. 28[1]	128	0	23–24	128	64.0	Mar. 28[1]	445	0	23–24	445	222.5
31	166	285	25–27	38	12.6	31	1,165	0	25–27	720	240.0
Apr. 6	886	640	28–33	720	120.0	Apr. 6	1,981	0	28–33	816	136.0
11	2,104	398	34–38	1,371	274.2	11	1,611	.....	34–38	555	111.0
16	3,131	280	39–43	1,520	304.0	16	2,658	.....	39–43	1,831	366.2
25	6,040	67	44–52	5,128	569.8	25	6,329	1	44–52	5,230	581.1
May 3	5,527	42	53–60	3,248	406.0	May 3	6,633	0	53–60	4,308	538.5
11	3,038	28	61–68	1,414	176.7	11	6,827	38	61–68	4,673	584.1
20	1,133	109	69–77	603	67.0	20	10,074	154	69–77	8,322	924.7
28	637	289	78–85	369	46.1	28	11,231	623	78–85	7,532	941.5

[1] Sealing began on the preceding day.

TABLE 5.—*Record of sealed brood and computed emergence of workers in package colonies at Somerset, Md., 1927*—Continued

COLONY NO. 403

Sealed-brood counts			Computed emergence of workers		
Date	Worker	Drone	Days after installing package	Emergence	Average daily emergence
Mar. 28[1]	674	.....	23–24	674	337.0
31	2,094	.....	25–27	1,420	473.3
Apr. 6	4,623	.....	28–33	2,529	421.5
11	4,465	.....	34–38	1,463	292.6
16	6,112	16	39–43	3,806	761.2
25	12,860	331	44–52	10,576	1,175.1
May 3	14,031	224	53–60	9,330	1,166.3
11	12,935	94	61–68	8,270	1,033.75
20	12,021	751	69–77	8,920	991.1
28	13,822	1,039	78–85	9,858	1,232.25

COLONY NO. 404

Mar. 31[2]	100	0	27	100	100.0
Apr. 6	4,705	0	28–33	4,605	767.5
11	6,825	0	34–38	2,120	424.0
16	7,669	0	39–43	4,014	802.8
25	13,012	347	44–52	10,604	1,178.2
May 3	15,977	622	53–60	11,264	1,408.0
11	16,812	560	61–68	11,180	1,397.5
20	15,655	790	69–77	11,462	1,273.55
28	13,538	779	78–85	8,444	1,055.5

COLONY NO. 405

Mar. 28[1]	544	0	23–24	544	272.0
31	2,473	0	25–27	1,929	643.0
Apr. 6	6,562	0	28–33	4,089	681.5
11	6,732	0	34–38	2,000	400.0
16	7,528	29	39–43	4,165	833.0
25	13,644	370	44–52	11,145	1,238.33
May 3	15,769	451	53–60	10,816	1,352.0
11	16,945	242	61–68	11,537	1,442.1
20	16,269	592	69–77	11,942	1,326.9
28	17,994	568	78–85	12,686	1,585.75

COLONY NO. 411

Apr. 7	20	0	27	20	20.0
11	257	.....	28–31	237	59.2
16	327	.....	32–36	70	14.0
25	899	.....	37–45	857	95.2
May 4	440	.....	46–54	154	17.1
			55–56	[3] 34	[3] 17.0

COLONY NO. 412

Apr. 4	6	0	24	6	6.0
6	87	0	25–26	81	40.5
11	202	.....	27–31	115	23.0
16	491	.....	32–36	295	59.0
25	1,346	1	37–45	1,169	129.9
May 4	710	.....	46–54	320	35.55
11	581	.....	55–61	403	57.55
21	368	.....	62–71	253	25.3
June 2	2,191	.....	72–83	2,191	182.58
			84	[3] 183	[3] 182.58

COLONY NO. 413

Sealed-brood counts			Computed emergence of workers		
Date	Worker	Drone	Days after installing package	Emergence	Average daily emergence
Apr. 6[4]	878	0	24–26	878	292.7
11	2,436	.....	27–31	1,558	311.6
16	4,788	.....	32–36	2,645	529.0
25	7,825	44	37–45	6,238	693.11
May 4	6,024	75	46–54	3,945	438.33
11	9,128	105	55–61	6,937	991.0
21	13,154	755	62–71	11,172	1,117.2
June 2	16,391	655	72–83	16,391	1,365.93
			84	[3] 1,366	[3]1,366.0

COLONY NO. 414

Apr. 6[1]	273	0	25–26	273	136.5
11	2,097	.....	27–31	1,824	364.8
16	4,763	.....	32–36	2,666	533.2
25	8,499	.....	37–45	6,899	766.6
May 4	6,523	1	46–54	4,223	469.2
11	9,984	15	55–61	7,638	1,091.1
21	16,420	97	62–71	14,238	1,423.8
June 2	17,605	333	72–83	17,605	1,467.08
			84	[3] 1,467	[3]1,467.0

COLONY NO. 415

Apr. 3	103	.....	23	103	103.0
6	1,295	0	24–26	1,192	297.3
11	3,315	0	27–31	2,020	404.0
16	6,735	1	32–36	3,920	784.0
25	11,010	214	37–45	8,658	962.0
May 4	11,907	223	46–54	9,021	1,002.3
11	14,090	164	55–61	9,078	1,296.9
21	14,296	362	62–71	11,702	1,170.2
June 2	15,277	756	72–83	15,277	1,273.1
			84	[3] 1,273	[3]1,273.0

COLONY NO. 421

Apr. 11	33	.....	23	33	33.0
16	975	.....	24–28	942	188.4
26	5,347	.....	29–38	4,970	497.0
May 5	3,827	2	39–47	2,336	259.55
13	7,509	55	48–55	6,471	808.9
23	12,162	22	56–65	10,545	1,054.5
June 3	13,996	259	66–76	12,942	1,176.54
			77	[3] 1,177	1,177.0

COLONY NO. 422

Apr. 11	51	..	23	51	51.0
12	178	.....	24	127	127.0
16	1,274	.....	25–28	1,096	274.0
26	7,439	19	29–38	6,891	689.1
May 5	9,140	32	39–47	7,073	785.85
13	8,555	78	48–55	5,412	676.5
23	11,232	237	56–65	9,879	987.9
June 3	11,293	253	66–76	10,305	936.8
			77	[3] 937	[3] 936.8

[1] Sealing began on the preceding day.
[2] The first date in each section of this table is the first day of sealing, unless otherwise noted.
[3] Estimated.
[4] First sealing occurred 2 days earlier.

TABLE 5.—*Record of sealed brood and computed emergence of workers in package colonies at Somerset, Md., 1927*—Continued

COLONY NO. 423

Date	Sealed-brood counts: Worker	Sealed-brood counts: Drone	Computed emergence of workers: Days after installing package	Computed emergence of workers: Emergence	Computed emergence of workers: Average daily emergence
Apr. 16	223	.....	28	223	223.0
25	5,517	.....	29–37	5,294	588.2
May 4	8,521	5	38–46	6,756	750.67
13	7,601	46	47–55	5,349	594.3
24	10,674	395	56–66	10,080	916.36
June 3	13,365	672	67–76	11,532	1,153.2
			77	[3] 1,153	[3]1,153.0

COLONY NO. 424

Apr. 14	34	.....	26	34	34.0
16	576	.....	27–28	542	271.0
26	6,419	232	29–38	5,877	587.7
May 5	8,433	434	39–47	6,670	741.1
13	8,928	295	48–55	5,964	745.5
23	8,965	478	56–65	7,474	747.4
June 3	11,163	457	66–76	10,416	946.9
			77	[3] 947	[3] 946.9

COLONY NO. 425

Apr. 11	31	....	23	31	31.0
12	45	.....	24	14	14.0
16	2,214	.....	25–28	2,169	542.2
26	9,217	42	29–38	8,133	813.3
May 5	12,740	51	39–47	10,300	1,144.44
13	12,883	230	48–55	8,305	1,038.1
			56	[3] 1,038	[3]1,038.0

COLONY NO. 431

Apr. 16	131	.....	22	131	131.0
25	3,215	.....	23–31	3,084	342.7
May 5	2,508	2	32–41	1,823	182.3
13	4,688	.....	42–49	3,959	494.9
24	9,202	22	50–60	8,707	791.6
June 3	13,774	291	61–70	12,191	1,219.1

COLONY NO. 432

Apr. 16	383	.....	22	383	383.0
25	6,260	....	23–31	5,877	653.0
May 6	4,250	.....	32–42	3,597	327.0
13	6,583	4	43–49	4,948	706.9
24	15,259	168	50–60	14,552	1,322.9
June 3	18,310	394	61–70	15,664	1,566.4

COLONY NO. 433

Apr. 16	169	.....	22	169	169.0
25	7,343	.....	23–31	7,174	797.1
May 5	6,297	.....	32–41	4,703	470.3
13	8,309	14	42–49	6,428	803.5
24	15,707	434	50–60	14,903	1,354.8
June 3	17,691	516	61–70	14,981	1,498.1

COLONY NO. 434

Apr. 16	281	.....	22	281	281.0
25	7,687	1	23–31	7,406	822.9
May 5	6,561	5	32–41	4,915	491.5
13	8,619	21	42–49	6,654	831.75
24	15,111	314	50–60	14,280	1,298.2
June 3	16,902	632	61–70	14,306	1,430.6

COLONY NO. 435

Apr. 16	256	.....	22	256	256.0
25	7,220	.....	23–31	6,964	773.78
May 5	6,030	7	32–41	4,482	448.2
13	8,944	66	42–49	7,151	893.9
24	10,901	138	50–60	10,007	909.73
June 3	12,984	194	61–70	11,165	1,116.5

COLONY NO. 441

Apr. 25[5]	770	.....	21–23	770	256.67
May 3	4,271	.....	24–31	3,501	437.6
13	4,771	5	32–41	3,896	389.6
24	7,733	13	42–52	7,343	667.5
June 4	12,249	85	53–63	11,581	1,052.8
16	13,116	362	64–75	13,116	1,093.0
25	14,929	401	76–84	11,650	1,294.4

COLONY NO. 442

Apr. 25[1]	387	.....	22–23	387	193.9
May 3	4,072	.....	24–31	3,685	460.6
13	3,301	11	32–41	2,380	238.0
24	7,558	5	42–52	7,320	665.46
June 4	12,525	197	53–63	11,859	1,078.1
16	13,598	315	64–75	13,598	1,133.14
25	16,735	258	76–84	13,335	1,481.7

COLONY NO. 443

Apr. 25[1]	674	.....	22–23	674	337.0
May 3	6,224	.....	24–31	5,550	693.75
13	6,907	31	32–41	5,520	552.0
24	11,269	64	42–52	10,717	974.3
June 4	15,332	209	53–63	14,358	1,305.3
16	15,493	61	64–75	15,495	1,291.1
25	15,899	139	76–84	12,026	1,336.22

COLONY NO. 444

May 3	682	.....	31	682	682.0
13	8,388	35	32–41	7,706	770.6
24	9,754	421	42–52	8,983	816.63
June 4	13,713	423	53–63	12,896	1,172.36
16	12,284	549	64–75	12,284	1,023.67
25	12,126	710	76–84	9,045	1,005.0

[1] Sealing began on the preceding day.
[3] Estimated.
[5] Only a few sealed worker cells were found on Apr. 23, but in the computations this date marks a full day's sealing.

TABLE 5.—*Record of sealed brood and computed emergence of workers in package colonies at Somerset, Md., 1927*—Continued

COLONY NO. 445

Date	Sealed-brood counts: Worker	Sealed-brood counts: Drone	Computed emergence of workers: Days after installing package	Computed emergence of workers: Emergence	Computed emergence of workers: Average daily emergence
Apr. 25[1]	637	-------	22–23	637	317.5
May 3	6,394	84	24–31	5,757	719.6
13	8,713	187	32–41	7,274	727.4
24	9,325	412	42–52	8,598	781.6
June 4	10,678	467	53–63	9,896	899.63
16	9,911	415	64–75	9,911	825.9
25	9,325	447	76–84	6,847	760.77

COLONY NO. 451

May 3[4]	1,700	-------	24–26	1,700	566.7
13	9,173	7	27–36	8,040	804.0
25	10,504	81	37–48	10,504	875.3
June 6	15,256	125	49–60	15,256	1,271.3
17	14,247	458	61–71	12,976	1,179.6
			72	[3] 1,225	[3]1,225.0
30	15,236	243	73–84	15,236	1,269.7

COLONY NO. 452

May 3[6]	2,343	-------	22–26	2,343	468.6
13	8,069	56	27–36	7,132	713.2
25	9,620	66	37–48	9,620	801.7
June 6	12,151	549	49–60	12,151	1,012.6
17	14,381	231	61–71	13,368	1,215.3
			72	[3] 1,208	[3]1,208.0
30	14,400	555	73–84	14,400	1,200.0

COLONY NO. 453

May 3[6]	3,557	13	22–26	3,557	711.4
13	13,467	97	27–36	12,044	1,204.4
25	15,339	435	37–48	15,339	1,278.3
June 6	18,219	625	49–60	18,219	1,518.3
17	19,444	656	61–71	17,926	1,629.6
29	16,942	678	72–83	16,942	1,411.8
			84	[3] 1,412	[3]1,412.0

COLONY NO. 454

May 3[1]	1,788	-------	25–26	1,788	894.0
13	10,531	63	27–36	8,743	874.3
25	11,270	515	37–48	11,270	939.2
June 6	16,209	486	49–60	16,209	1,350.75
17	16,435	442	61–71	15,084	1,371.3
			72	[3] 1,408	[3]1,407.5
30	17,324	654	73–84	17,324	1,443.7

COLONY NO. 455

Apr. 28[7]	4	-------	21	4	4.0
May 3	3,988	-------	22–26	3,984	796.8
13	14,597	59	27–36	13,003	1,300.3
25	14,482	64	37–48	14,482	1,206.8
June 6	15,540	87	49–60	15,540	1,295.0
17	12,094	2	61–71	10,799	981.7
29	10,927	3	72–83	10,927	910.6
			84	[3] 911	[3] 910.6

COLONY NO. 463

May 11[6]	2,408	-------	22–26	2,408	481.6
			27–28	1,493	746.5
25	12,138	36	29–40	12,138	1,011.5
June 6	13,199	125	41–52	13,199	1,099.9
17	16,198	485	53–63	15,098	1,372.6
29	17,936	372	64–75	17,936	1,494.7
July 8	16,140	349	76–84	11,656	1,295.1

COLONY NO. 471

May 21[8]	1,524	-------	24–29	1,524	254.0
June 1	2,610	-------	30–40	2,356	214.2
13	5,404	-------	41–52	5,404	450.3
23	8,620	-------	53–62	7,719	771.9
July 5	10,911	4	63–74	10,911	909.2
15	10,665	123	75–84	8,847	884.7

COLONY NO. 472

May 13[7]	1	-------	21	1	1.0
21	6,538	14	22–29	6,537	817.1
June 1	11,829	125	30–40	11,012	1,001.1
13	13,447	165	41–52	13,447	1,120.6
23	17,033	252	53–62	14,792	1,479.2
July 5	19,315	233	63–74	19,315	1,609.6
15	17,070	259	75–84	13,851	1,385.1

COLONY NO. 473

May 21[8]	6,450	2	24–29	6,450	1,075.0
June 1	12,826	40	30–40	11,751	1,068.3
13	11,936	31	41–52	11,936	994.7
23	17,369	195	53–62	15,380	1,538.0
July 5	19,756	105	63–74	19,756	1,646.3
15	16,091	254	75–84	12,798	1,279.8

[1] Sealing began on the preceding day.
[3] Estimated.
[4] First sealing occurred 2 days earlier.
[6] First sealing occurred four days earlier.
[7] Obviously not a full day.
[8] First sealing occurred five days earlier.

TABLE 5.—*Record of sealed brood and computed emergence of workers in package colonies at Somerset, Md., 1927*—Continued

COLONY NO. 475

Sealed-brood counts			Computed emergence of workers		
Date	Worker	Drone	Days after installing package	Emergence	Average daily emergence
May 21[9]	7,133	6	22–29	7,133	891.6
June 1	13,476	14	30–40	12,584	1,144.0
13	14,265	379	41–52	14,265	1,188.7
23	17,574	461	53–62	15,197	1,519.7
July 5	15,065	853	63–74	15,065	1,255.4
15	10,566	478	75–84	8,055	805.5

COLONY NO. 491

June 2[4]	2,791	0	24–26	2,791	930.3
			27	[3] 708	[3] 707.5
15	5,817	7	28–39	5,817	484.75
27	8,772	4	40–51	8,772	731.0
July 8	12,107	0	52–62	11,376	1,034.2
19	11,151	0	63–73	10,117	919.7
30	12,489	0	74–84	11,569	1,051.7

COLONY NO. 492

May 28[7]	1	0	21	1	1.0
June 2	1,645	0	22 26	1,644	328.8
			27	[5] 490	[3] 490.0
15	7,821	0	28–39	7,821	651.75
27	8,264	0	40–51	8,264	688.7
July 8	10,408	1	52–62	9,719	883.6
19	8,698	0	63–73	7,815	710.4
30	7,743	0	74–84	7,033	639.4

COLONY NO. 493

Sealed-brood counts			Computed emergence of workers		
Date	Worker	Drone	Days after installing package	Emergence	Average daily emergence
June 2[1]	1,619	.....	25–26	1,619	809.5
			27	[3] 803	[3] 803.0
15	9,557	296	28–39	9,557	796.4
27	10,201	377	40–51	10,201	850.1
July 8	12,466	277	52–62	11,616	1,056.0
19	7,789	.....	63–73	6,733	612.1
30	8,490	1	74–84	7,878	716.2

COLONY NO. 494

May 28[7]	4	.....	21	4	4.0
June 2	3,978	.....	22–26	3,974	794.8
			27	[3] 902	[3] 902.0
15	12,100	19	28–39	12,100	1,008.3
27	12,347	9	40–51	12,347	1,028.9
July 8	14,542	.....	52–62	13,513	1,228.4
20	12,248	.....	63–74	12,248	1,020.66
Aug. 1	11,147	.....	75–86	11,147	928.9

COLONY NO. 495

June 2[4]	1,080	.....	24–26	1,080	360.0
			27	[3] 433	[3] 443.0
15	6,277	131	28–39	6,277	523.0
27	13,858	129	40–51	13,858	1,154.8
July 8	15,015	117	52–62	13,860	1,260.0
20	11,870	3	63–74	11,870	989.15
Aug. 1	12,007	.....	75–86	12,007	1,000.5

[1] Sealing began on the preceeding day.
[3] Estimated.
[4] First sealing occurred 2 days earlier.
[7] Obviously not a full day.
[9] A few sealed cells were found on May 13 but these have been disregarded in the computation.

DISCUSSION OF FACTS BROUGHT OUT IN 1927 BY PACKAGE COLONIES AS A WHOLE

WEIGHT OF LIVE BEES IN PACKAGE ON ARRIVAL IN COMPARISON WITH WEIGHT BILLED BY SHIPPER

Since each of the weekly lots consisted of one 1-pound, one 2-pound, one 3-pound, one 4-pound, and one 5-pound package, the total weight of bees in each shipment should have been 15 pounds. Furthermore, since 10 shipments in all were received, the total weight of bees in these 10 shipments should have been 150 pounds. As a matter of fact, when the individual weights of live bees in all the packages are added the total (Table 6) is found to be 152⅔ pounds. The total weight of bees in the 40 colonies actually used in the experiment in 1927 should have been 119 pounds, but the actual live weight received was 120 pounds.

TABLE 6.—*Weight of live bees in packages when received at Somerset, Md., 1927*

Weight of bees called for in the order	Weight of live bees in packages in—											
	Lot 1		Lot 2		Lot 3		Lot 4		Lot 5		Lot 6	
Pounds	*Pounds*	*Kilos*	*Pounds*	*Kilos*	*Pounds*	*Kilos*	*Pounds*	*Kilos*	*Pounds*	*Kilos*	*Pounds*	*Kilos*
1	1.56	0.71	1.47	0.67	1.21	0.55	0.79	0.36	1.91	0.87	1.63	0.74
2	1.94	.88	2.13	.97	2.51	1.14	2.13	.97	1.83	.83	1.98	.90
3	2.95	1.34	3.59	1.63	2.99	1.36	3.17	1.44	2.71	1.23	3.45	1.57
4	3.92	1.78	4.20	1.91	4.27	1.94	2.84	1.29	3.85	1.75	4.05	1.84
5	5.32	2.42	5.19	2.36	4.20	1.91	2.49	1.13	4.20	1.91	6.45	2.93
Total	15.69	7.13	16.58	7.54	15.18	6.90	11.42	5.19	14.50	6.59	17.56	7.98
	Lot 7		Lot 8		Lot 9		Lot 10		Total		Average	
1	1.32	0.60	0.64	0.29	2.51	1.14	1.47	0.67	14.51	6.60	1.451	0.66
2	2.22	1.01	2.11	.96	2.86	1.30	2.33	1.06	22.04	10.02	2.204	1.002
3	3.08	1.40	3.12	1.42	2.93	1.33	3.37	1.53	31.36	14.25	3.136	1.425
4	4.14	1.88	2.90	1.32	5.08	2.31	4.47	2.03	39.72	18.05	3.972	1.805
5	4.86	2.21	4.00	1.82	3.89	1.77	4.47	2.03	45.07	20.49	4.507	2.049
Total	15.62	7.10	12.77	5.81	17.27	7.85	16.11	7.32	152.70	69.41	15.27	6.941

In the foregoing totals the weight of dead bees is not included; this weight (Table 7) was almost 3¼ pounds on the basis of 5,000 bees to the pound. This is slightly more than 2 per cent of the weight called for in the total order, or of the total poundage shipped. Although the weight of live bees when received favored the purchaser, yet an actual loss in dead bees of even 2 per cent seems higher than necessary, especially when it is noted that six packages (Nos. 402, 431, 435, 442, 443, and 474) furnished about half of the total number of dead bees. The number in each of the packages ranged from 1,105 to 1,870. No particular reason was found for this heavy mortality save in the case of No. 431, in which the 1,374 dead bees may be accounted for in part by the fact that the sirup container had no hole and so the bees had no access to the feeder. All of the other five packages had taken sirup, some of them quite abundantly, but none were out of sirup.

TABLE 7.—*Number of dead bees in packages on arrival*

Package No.	Dead bees	Package No.	Dead bees	Package No.	Dead bees	Package No.	Dead bees
401	660	424	100	452	71	475	695
402	1,870	425	100	453	16	481	50
403	330	431	1,374	454	200	482	150
404	220	432	100	455	80	483	120
405	15	433	200	461	35	484	250
411	90	434	150	462	220	485	75
412	52	435	1,127	463	100	491	110
413	50	441	636	464	230	492	100
414	45	442	1,450	465	100	493	75
415	125	443	1,642	471	25	494	250
421	45	444	372	472	10	495	175
422	50	445	944	473	75		
423	100	451	50	474	1,105	Total	16,214

Of the other 44 packages, 25 had 100 or less dead bees; 8 had between 101 and 200 dead bees; 5 had between 201 and 300; while the other 6 had between 301 and 1,000. There were no signs that starvation played much part in the loss occurring in these 44. The bees

in each package had taken sirup on the railroad trip, but on arrival, with only 7 exceptions, each package still had over 100 grams of sirup in the can. Packages Nos. 412 and 444 had 10 and 20 grams, respectively, while packages Nos. 475, 481, 493, 494, and 495 arrived with their sirup cans empty. Package No. 475, with 695 dead bees, had the largest number of dead bees of any of these 7 packages, while package No. 481, with 50 dead bees, had the smallest number. None of the seven packages arriving with the smallest quantities of sirup in their feeder cans were among the six showing the highest mortality.

The average weights of the individuals (Table 9) in the seven foregoing packages give no indication of starvation since only one (No. 494) shows a low figure (107.25 mgm) in this respect. As a matter of fact, No. 472, which had the lowest average weight for individuals of any of the 45 packages for which these data were determined, arrived with sirup left in its feeder can and had only 10 dead bees.

The mere presence of sirup in the can does not necessarily mean in itself an abundance of sirup available to the bees, because the sirup may not have passed readily from the can. Possibly this was a contributing cause of the high mortality rate in No. 474, even though the fact that this package had a low average weight for individuals and when received had over 100 grams of sirup left in the feeder can does not differentiate it from No. 472.

The individual lots and the packages within each lot display a wide variation. The total live weights for the separate lots varied from 11.42 pounds to 17.56 pounds. (Table 6.) As for the individual packages, in no instance did the 1-pound package contain exactly 1 pound of live bees. Often it weighed more, but sometimes it weighed less. The one in lot No. 8, for instance, contained only 0.64 pound, while the one in lot No. 9 contained 2.51 pounds. Varying values for the other lots could be cited. The range for the 2-pound package was somewhat less, the minimum being 1.83 pounds (that in lot No. 5) and the maximum 2.86 pounds (that in lot No. 9). The 3-pound package ranged from 2.71 up to 3.59 pounds. The 4-pound package fluctuated about as widely as did the 1-pound package, ranging from 2.84 to 5.08 pounds. The 5-pound package fluctuated even more widely, ranging from 2.49 to 6.45 pounds, and in only three lots did it contain 5 pounds of bees or more. If these packages are typical of the ordinary run of commercial packages, such wide variations in the actual weights may account in part for the widely different results sometimes reported from packages of different sizes. It could not be expected that a supposedly 1-pound package which really contained 2½ pounds would compare other than favorably with a 3-pound package, especially if the latter happened to be a little underweight, or even with a supposed 5-pound package which really contained only 2½ pounds, as did one package in this experiment.

Under a system whereby the bees are weighed as shaken, errors on the part of the helpers are to be expected, when all the conditions under which bees are shaken are taken into consideration. Errors would naturally be greatest in packages of about the 1-pound size because 1 pound may be so quickly shaken in directly from the frame or let in from a container that it is easy to get over the mark. Once the bees are in, it is less bother as well as less painful to nail the package up rather than to let out or remove the excess bees, expecially when they have become angry. On the other hand, before a 5-pound

package is completely filled the bees already in the package have had sufficient time to become quite stirred up and to make vigorous attempts to get out of the funnel. If, in addition, the last colony from which bees are being shaken does not furnish quite enough bees to reach the 5-pound mark, a tendency to stop short of the mark, with the thought that a few more or less matters little, might well be expected. That such actually is the case seems evident from the averages for the various packages. Thus (Table 6) the 1-pound packages averaged nearly one-half pound overweight, the actual average being 1.451 pounds. The 5-pound packages averaged nearly one-half pound underweight, their actual average being only 4.507 pounds. The 2-pound packages were one-fifth of a pound overweight. The 3-pound packages averaged about 0.14 pound overweight; while the average of the 4-pound package was a mere trifle underweight, the exact amount of shortage being 0.028 pound.

If the foregoing conditions are general, even though the package shipper loses nothing, owing to the fact that the average of the weights of all his packages irons out to the proper figure in the long run, yet individual purchasers of the bees here and there lose money on their orders, while others obtain an undeserved gain. Since it seems hard to get accurate weighings at the time of shaking, and since it is a simple matter to have shipping containers of a standard weight as well as feed cans which contain a standard weight of a given sirup, it would seem a simple and businesslike procedure to weigh each package again at the station or elsewhere just before shipping, to deduct the proper tare to cover shipping cage and food, and to charge the purchaser only for the weight of bees actually in the package.

Under the foregoing plan, the shipper could collect for only 2½ pounds of bees in the case of package 435, received on April 6, instead of receiving pay for a 5-pound package. On the other hand, he would receive pay for 2½ pounds of bees instead of for only 1 pound in cases like package No. 481, received on May 11. Such a scheme would entail little additional burden on the shipper. The result would be full value to the buyer at least in respect to weight, and, on the other hand, full value to the shipper for every pound sold, regardless of accuracy or its lack on the part of those doing the shaking.

Of course it would be far better for the purchaser to get the exact weight he orders in each package, because if he decides he needs a certain number of 3-pound packages for a certain purpose he does not order on the basis of total poundage but of individual units. Otherwise he would order only in terms of total poundage. Consequently, in the example given, although the total poundage would be the same, he would not want half of his packages to contain only 1½ pounds and the other half to contain 4½ pounds, because the strength of the packages would be too unequal for his purpose, and he ought not to be given the task of taking from one and adding to the other in order to equalize them.

RELATION BETWEEN NUMBER OF BEES IN PACKAGE AS COMPUTED ON BASIS OF INDIVIDUAL SAMPLE AND BASIS OF 5,000 BEES TO THE POUND

The numbers of bees in each package, computed on the basis of the individual weights derived from the representative sample (Table 8), also show wide variation. Thus the 4-pound package of lot 2, on March 23, contained 4.2 pounds of live bees, as did the 5-pound

packages of lot 3 on March 31 and of lot 5 on April 14. Yet for the 4-pound package of lot 2 the computation gives 14,585 bees; for the 5-pound package of lot 3, 13,066 bees; and for the 5-pound package of lot 5, only 11,365 bees, a number about 20 per cent lower than that computed for the 4-pound package of lot 2. As another example, the 4-pound package in lot 10 on arrival contained 4.47 pounds of live bees while the 5-pound package in lot 6 contained 6.45 pounds, being about 40 per cent heavier, yet the computed total for the latter in bees, 19,376, was only 448 more than that computed for the former. As an extreme case, package No. 445 contained over 1¼ pounds more live bees than did package 474, but its computed total of individual bees was less. These variations are due obviously to variations in the average weights of individual bees in each package. Such variations in turn may probably be explained, in part at least, by the size of the load of food carried. In this connection, since the bees in the samples had been confined not more than three days, the rectal content is disregarded.

TABLE 8.—*Number of live bees in packages on arrival* [1]

Package No.	Worker bees	Package No.	Worker bees	Package No.	Worker bees	Package No.	Worker bees
411	5,044	433	10,715	455	19,376	482	9,049
412	7,754	434	8,638	461	4,306	483	9,029
413	11,985	435	7,294	462	7,429	484	16,145
414	14,585	441	6,680	463	10,755	485	12,334
415	17,229	442	6,573	464	14,329	491	6,413
421	3,952	443	10,120	465	14,288	492	8,937
422	8,129	444	13,629	471	2,199	493	10,918
423	10,021	445	11,365	472	9,346	494	18,928
424	14,836	451	5,831	473	10,147	495	16,603
425	13,066	452	5,622	474	12,241		
431	3,175	453	10,300	475	14,527		
432	6,519	454	14,671	481	8,678		

[1] Computed from data in Tables 6 and 9.

In Table 9, showing average individual weights in samples of bees, the minimum average is 102.71 mgm, and the maximum 168.06 mgm. On the other hand, if a pound of bees contains 5,000 bees on an average (*34, p. 760*), the average weight of an individual bee is 90.91 mgm. In no case, as just pointed out, was such a low figure found. Obviously, therefore, under these conditions, computing the number of bees in the packages on a basis of 5,000 bees to the pound would give totals different from those obtained by using the average individual weight of bees in a representative sample. For instance, package 421 arrived with 1.2 pounds of living bees, which, at 5,000 bees per pound, would mean 6,000 bees. On the basis of individual weights (Table 10) the number was 3,952, or less than two-thirds as many.

TABLE 9.—*Average weight of bees in samples from 45 packages, 1927*

Lot No.[1]	Size of package as billed	Bees in sample	Weight of sample	Average weight of individual bees	Lot No.[1]	Size of package as billed	Bees in sample	Weight of sample	Average weight of individual bees
	Pounds	*Number*	*Mgm*	*Mgm*		*Pounds*	*Number*	*Mgm*	*Mgm*
2	1	51	6,774	132.82	7	1	85	11,844	139.34
	2	52	6,505	125.10		2	57	7,749	135.95
	3	50	6,800	136.00		3	93	12,106	130.17
	4	45	5,893	130.96		4	65	8,528	131.20
	5	48	6,575	136.98		5	83	12,838	154.67
3	1	51	7,097	136.16	8	1	80	10,552	131.90
	2	49	6,970	140.24		2	80	8,217	102.71
	3	79	10,722	135.72		3	78	10,915	139.94
	4	63	8,238	130.76		4	94	10,136	107.83
	5	68	9,940	146.18		5	71	8,895	125.28
4	1	105	11,905	113.38	9	1	69	9,064	131.36
	2	61	9,077	148.80		2	62	8,907	143.66
	3	83	11,154	134.39		3	70	10,311	147.30
	4	65	9,707	149.34		4	91	13,020	143.08
	5	90	13,944	154.93		5	74	10,620	143.51
5	1	83	10,810	130.24	10	1	58	6,060	104.48
	2	64	8,081	126.27		2	122	14,471	118.61
	3	78	9,480	121.54		3	111	15,556	140.14
	4	95	12,198	128.40		4	125	13,406	107.25
	5	84	14,117	168.06		5	86	10,515	122.27
6	1	79	10,026	126.91	Total		3,522	471,910	
	2	71	11,366	160.08	Average weight of bees in samples				133.99
	3	126	19,206	152.43	Weighted average[2] individual weight of bees in the packages				135.85
	4	111	13,922	125.42					
	5	117	17,693	151.22					

[1] Samples were not taken from lot No. 1.
[2] Method of obtaining this weighted average is given on p. 24.

Since in every case the average individual weight of the workers in the packages is appreciably greater than 90.91 mgm it may be assumed that the difference is made up by the weight of honey or sugar sirup taken by the bee when smoked just prior to shaking, or else taken from the feeder during shipment. It has been reported that bees at times may carry their own weight in honey in their honey sacs. This condition was not quite reached in any of the packages, if we accept the average weight of the worker bee as 90.91 mgm, because the highest average individual weight is only 168.06 mgm.

The total number of bees in the samples taken from the 45 packages in lots 2 to 10, inclusive, was 3,522. Since their total weight was 471,910 mgm, the unweighted average individual weight is 133.99 mgm. The weighted average, obtained by first multiplying the average individual weight calculated for each package (Table 9) by the weight of living bees determined for that package (Table 6) and then dividing the sum of these products by the sum of the live weights of all of these packages, is a trifle larger than the unweighted average, being 135.85 mgm. This figure is very nearly one and one-half times as large as 90.91 mgm, the figure commonly accepted in this country as the average weight of empty bees, and may mean that the bees in the packages were carrying nearly half their weight in honey or sugar.

In other words, one-third of the weight of the bees at the time they arrived was really sugar sirup or honey in their honey sacs. Whether they carried this much when they were placed in the packages is another matter, but if they had no honey in their honey sacs when they were shaken into the containers, and if they made up the difference in average weight by sirup taken on the trip, then the total

poundage of bees was one-third underweight when shipped. This does not seem likely.

Although it is only to be expected that bees when shaken into packages will be carrying some honey in their honey sacs, the amount will vary under different conditions and manipulations. Certain producers may use every care to avoid disturbances which cause the bees to fill their honey sacs at the time of shaking; others, intentionally or not, may so manipulate the bees prior to the shaking process that the bees will have a maximum load in their honey sacs when they are put into the shipping cages. Under these two extremes a pound of bees of uniform size would vary in the number of bees it contained; a pound put up under the last mentioned conditions would contain fewer bees but more honey or sirup. Until some method is arrived at of selling bees more nearly on the basis of numbers instead of weight, the purchaser may at times be buying more honey and fewer bees than he is aware of.

IMPORTANCE OF QUANTITY OF BEES IN PACKAGE

The relative importance of different-sized packages of bees depends on the use to which they are to be put and the time when they are received. If they are bought primarily to build up into colonies to gather the honey flow or to act as pollenizers, their proper size will be governed somewhat by the time available for them to build up. Obviously, the shorter the time, the larger should be the package. If they are bought solely to act as pollenizers, the package should certainly be as large as practicable. If they are bought to reinforce an established colony, the foregoing considerations would also seem to govern.

RELATION BETWEEN SIZE OF PACKAGE AND RAPIDITY OF BUILDING UP

The rapidity with which a colony builds up is of course dependent on a number of factors, which include the number of bees on hand, the prolificness of the queen, weather conditions, and the quantity of nectar and pollen available. In this experiment, as already mentioned, an endeavor was made to provide uniform queens and food in abundance for the colonies. The weather early in the experiment was somewhat unseasonable at times, but on the whole proved favorable in the case of most of the colonies. Hence, at this point only the question of size of package as related to rapidity of building up will be discussed.

In a tabulation (Table 10) by colonies, showing the weekly population in bees reared after the packages were installed, arranged in the order of the number of bees in the packages when they were received, with few exceptions a general tendency for the larger packages to build up more quickly into a higher total population is apparent. This is also shown graphically in Figure 3. If the packages are divided into two groups, the first comprising those packages with 10,021 bees or fewer when received, and the other those packages with more than this number, 17 colonies fall within the first group and 18 within the second. Eight weeks after being received, only 2 of the first 17 colonies, or roughly 12 per cent, had over 30,000 bees, while 7 of the last 18, or roughly 40 per cent, had this number or more. In the next week these figures had moved up to four-sixteenths (25 per cent) and thirteen-seventeenths (over 75 per cent) respectively,

1 colony having dropped out of each group (Nos. 411 and 425) for reasons mentioned earlier.

The highest population computed for any colony in the course of the first eight weeks was 43,000 in No. 453, while No. 455 was second with 41,800. The computed number of bees in No. 453 on arrival was 10,300 while No. 455 had the most of any of the 35 packages, 19,376. Of the second group, 3 had already reached 40,000 or more by the end of the eighth week, but none of the first group had done so. Five of the second group had 35,000 or more, but the same can be said of only 1 of the first group, and this was the second strongest package in this group originally. Fourteen packages in the second group had 25,000 or more, but only 5 of the first group exceeded the 25,000 point.

TABLE 10.—*Computed worker populations for successive weeks after installing package colonies used in 1927, arranged in order of package strength computed on basis of representative sample*

Colony No.	Computed number of bees in package when received	Computed number of bees in colony at end of number of weeks specified [1]								
		4	5	6	7	8	9	10	11	12
471	2,199	1,270	2,809	4,781	7,933	12,372	16,643	21,468	25,787	28,828
431	3,175	2,187	3,944	5,533	8,997	14,538	19,390	26,671	.....	.....
421	3,952	975	4,459	6,983	9,899	15,807	22,214	26,726	32,433	.....
411	5,044	79	313	898	1,252	1,372	.....	.....	.....	.....
452	5,622	3,769	8,761	14,284	20,107	27,195	31,122	34,637	37,537	40,114
451	5,831	3,308	8,936	14,992	21,515	30,414	35,730	38,359	41,056	43,421
491	6,413	3,984	7,377	11,509	16,626	23,259	26,400	29,445	32,279	34,524
432	6,519	4,301	7,568	9,857	14,805	24,065	29,755	37,453	.....	.....
442	6,573	2,690	5,024	7,118	11,776	18,084	22,941	28,539	35,074	40,788
441	6,680	2,958	5,829	8,834	13,507	19,464	24,133	28,913	33,962	38,350
435	7,294	4,899	9,013	12,596	18,853	25,221	27,310	31,012	.....	.....
412	7,754	133	438	1,276	1,808	2,101	2,306	2,178	2,461	3,207
422	8,129	1,274	6,098	11,309	16,591	21,638	27,279	29,115	30,462	.....
434	8,638	5,218	9,653	13,434	19,256	28,343	32,610	38,189	.....	.....
492	8,937	2,787	7,349	12,022	16,843	22,637	25,863	26,274	26,290	25,945
472	9,347	5,720	12,554	19,791	27,635	36,914	41,679	46,122	49,469	51,321
423	10,021	223	4,340	9,270	14,056	18,538	24,730	27,975	31,117	.....
443	10,120	4,143	8,432	12,718	19,538	27,682	32,676	37,425	42,266	44,800
473	10,147	5,375	12,860	20,191	27,154	36,290	41,789	45,828	48,922	50,918
453	10,300	5,966	14,398	23,271	32,459	43,087	48,083	51,059	52,285	52,980
433	10,715	4,952	9,224	12,849	18,474	27,958	32,919	39,134	.....	.....
463	10,755	3,901	10,981	18,238	25,937	34,727	40,434	43,817	46,624	47,991
493	10,918	3,218	8,793	14,529	20,480	27,460	31,190	29,900	28,865	27,927
445	11,365	4,235	9,303	14,449	19,920	25,864	27,926	28,639	29,144	28,998
413	11,985	1,501	4,551	9,239	13,072	17,246	22,934	27,704	32,328	38,057
425	13,066	2,214	7,907	14,925	22,724	29,991	.....	.....	.....	.....
444	13,629	.....	3,764	9,204	14,920	22,059	30,266	33,668	35,356	36,675
475	14,527	6,241	13,997	22,094	30,415	40,060	44,192	45,224	44,565	41,882
414	14,585	1,003	4,230	9,363	13,540	18,068	25,368	32,108	37,201	43,294
454	14,671	3,537	9,657	16,167	23,153	32,609	38,589	42,068	45,556	48,676
424	14,836	576	4,690	9,418	14,615	19,835	24,491	26,606	28,506	.....
495	16,603	2,049	5,731	11,299	19,383	27,993	34,493	37,735	39,125	38,045
415	17,229	2,103	6,451	13,007	19,902	27,507	34,229	38,072	40,325	42,342
494	18,928	5,882	12,946	20,066	27,268	35,464	37,971	38,058	37,807	37,107
455	19,376	6,589	15,691	24,232	32,768	41,829	43,369	41,139	39,044	36,882
401	[2]	286	1,434	3,473	7,196	10,529	12,397	12,267	10,697	7,297
402	[2]	1,301	2,203	4,001	7,854	11,751	14,356	18,224	22,899	25,637
403	[2]	2,516	5,208	9,131	16,943	25,133	30,383	34,842	37,857	38,671
404	[2]	868	5,553	10,036	17,908	27,075	36,031	40,881	45,313	44,830
405	[2]	3,155	7,362	11,894	20,157	29,280	35,859	41,517	46,273	49,110

[1] Only bees reared after installing the packages are considered in the computations. From the computations given in Table 5 a few bees emerged in colonies Nos. 441, 455, 472, 475, 492, and 494, even on the twenty-first day after installation, the last day of the third week.

[2] Number of bees in package when received was not computed.

In relative rate of increase, the smaller packages appear at an advantage. If the package containing the largest number of bees when received, No. 455, is used as a base, it is easy to determine the ratio between the population of this package and that of any of the other packages when received by dividing the number of bees in the

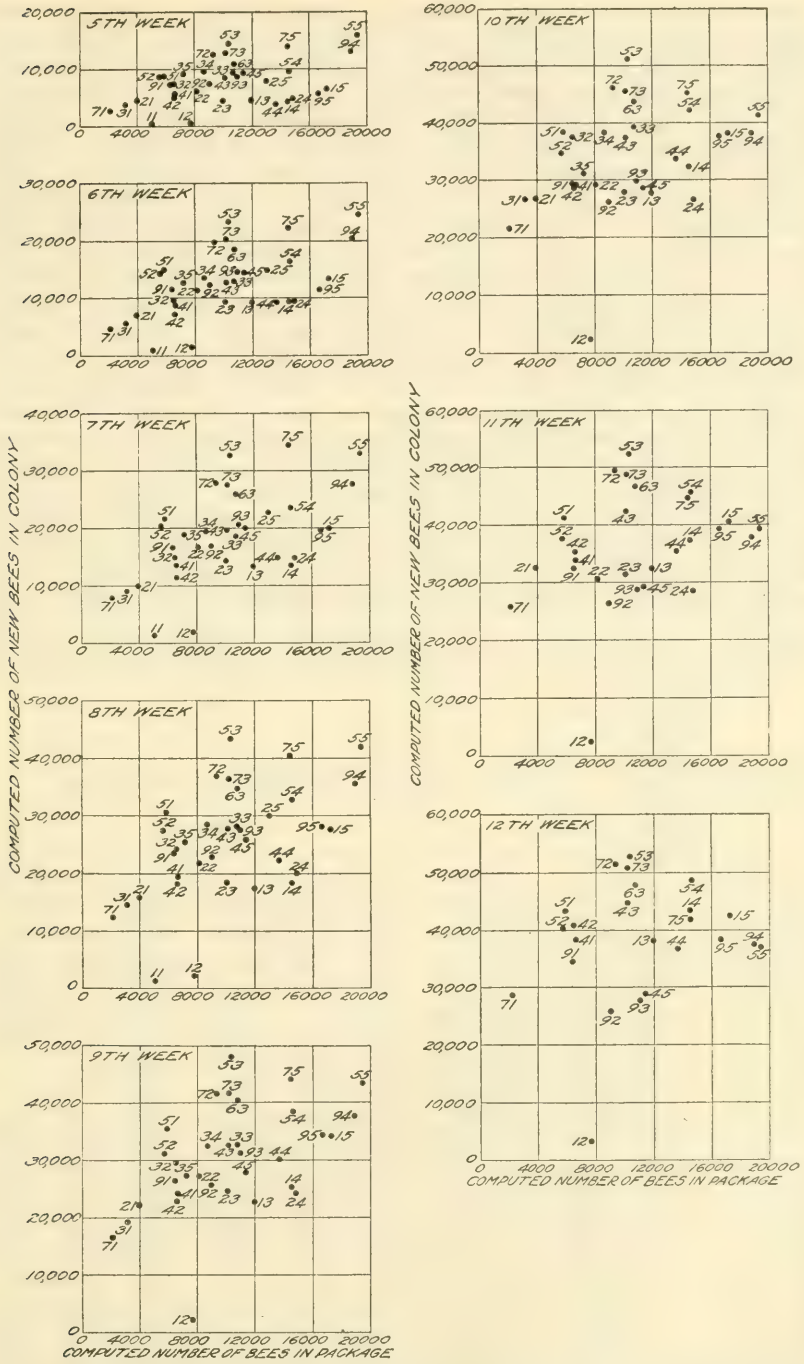

FIGURE 3.—Computed number of new bees in package colonies in specified weeks after installation in 1927. Each colony is represented by a dot and is identified by the last two figures of the number assigned to it. The horizontal position of each dot indicates the computed number of bees in the package when it was received. The vertical position of each dot indicates the computed number of bees present that were reared after the package was installed

latter into that in No. 455. Thus it is seen (Table 11) that No. 455 had 8.81 times as many bees when received as did No. 471; in other words, No. 455 would have made 8.81 packages the size of No. 471. If the computed population in No. 471 at the end of 12 weeks is multiplied by 8.81, it is evident that 8.81 packages the size of No. 471 at this time would have had 253,975 worker bees on hand, theoretically. This number is nearly seven times the number computed as being in No. 455 at the end of the same period. All the other packages show roughly the same tendency in a degree varying directly with their original population. It should be pointed out, however, that No. 471 at its height of population (28,828) at the end of the twelfth week actually had less than 70 per cent as many bees as No. 455 at the height of its population (43,369) at the end of the ninth week. At the latter date the equivalent of 8.81 packages, each the size of No. 471 originally, would have had a collective population (8.81 × 16,643) only about 3⅜ times as great as that of No. 455. The comparative cost in honey, and otherwise, of producing all these bees in both cases is not under consideration at this time. No. 455 apparently was not laboring under ideal conditions for brood rearing, since No. 453, which began its career with only a little over half the number of bees in No. 455, at the end of the ninth week had nearly 5,000 more bees. This colony led all others in maximum population attained during the experiment, having 52,980 bees at the end of the twelfth week.

TABLE 11.—*Converted populations of colonies obtained by multiplying the computed population of each colony by a factor equal to the ratio of the original population of package No. 455 to that of each package in question*

Colony No.	Ratio between No. 455 and each package when received	Converted population at end of number of weeks specified								
		4	5	6	7	8	9	10	11	12
471	8.81	11,189	24,747	42,120	69,890	108,997	146,625	189,133	227,183	253,975
431	6.10	13,341	24,058	33,751	54,882	88,682	118,279	162,693	.....	.....
421	4.90	4,778	21,849	34,217	48,505	77,454	108,849	130,957	158,922	.....
411	3.84	303	1,202	3,448	4,808	5,268	.....	.....	.....	.....
452	3.45	13,003	30,225	49,280	69,369	93,823	107,371	119,498	129,503	138,393
451	3.32	10,983	29,668	49,773	71,430	100,974	118,624	127,352	136,306	144,158
491	3.02	12,032	22,279	34,757	50,211	70,242	79,728	88,924	97,483	104,262
432	2.97	12,774	22,477	29,275	43,921	71,473	88,372	111,235	.....	.....
442	2.95	7,936	14,821	20,998	34,739	53,348	67,676	84,190	103,468	120,325
441	2.90	8,578	16,904	25,619	39,170	56,446	69,986	83,848	98,490	111,215
435	2.66	13,031	23,975	33,505	50,149	67,088	72,645	82,492	.....	.....
412	2.50	332	1,095	3,190	4,520	5,252	5,765	5,445	6,152	8,018
422	2.38	3,032	14,513	26,915	39,487	51,498	64,924	69,293	72,500	.....
434	2.24	11,688	21,623	30,092	43,133	63,488	73,046	85,543	.....	.....
492	2.17	6,048	15,947	26,088	36,549	49,122	56,123	57,015	57,019	56,301
472	2.07	11,840	25,987	40,967	57,204	76,412	86,276	95,473	102,401	106,234
423	1.93	430	8,376	17,891	27,128	35,778	47,729	53,992	60,056	.....
443	1.91	7,913	16,105	24,291	37,318	52,873	62,411	71,482	80,728	85,568
473	1.91	10,266	24,563	38,565	51,864	69,314	79,817	87,531	93,441	97,253
453	1.88	11,216	27,066	43,749	61,023	81,004	90,396	95,991	98,296	99,602
433	1.81	8,963	16,695	23,257	33,438	50,604	59,583	70,833	.....	.....
493	1.80	7,022	19,766	32,828	46,687	62,509	72,781	78,871	83,923	86,384
493	1.77	5,696	15,564	25,716	36,250	48,604	55,206	52,923	51,091	49,431
445	1.70	7,200	15,815	24,563	33,864	43,969	47,474	48,686	49,545	49,297
413	1.62	2,432	7,373	14,967	21,177	27,939	37,153	44,880	52,371	61,652
425	1.48	3,277	11,702	22,089	33,632	44,387	.....	.....	.....	.....
444	1.42	.....	5,345	13,070	21,186	31,324	42,978	47,809	50,206	52,078
475	1.33	8,301	18,616	29,385	40,452	53,280	58,775	60,148	59,271	55,703
414	1.33	1,369	5,625	12,452	18,008	24,030	33,739	42,703	49,477	57,581
454	1.32	1,669	12,747	21,340	30,562	43,044	50,937	55,530	60,134	64,252
424	1.31	755	6,144	12,338	19,146	25,984	32,083	34,854	37,343	.....
495	1.17	2,397	6,705	13,220	22,678	32,752	40,357	44,150	45,776	44,513
415	1.12	2,355	7,225	14,568	22,290	30,808	38,336	42,641	45,164	47,423
494	1.02	6,006	13,206	20,467	27,813	36,173	38,730	38,819	38,563	37,849
455	1.00	6,589	15,691	24,232	32,768	41,829	43,369	41,139	39,044	36,882

For relative increase in population, therefore, there seems in this experiment some advantage in using an equivalent number of smaller packages in place of one large package, provided there is sufficient time to build up. On the other hand, in this experiment, it was the larger packages which gave quick results, such as are so highly desirable in cold weather, or if the package bees are to be used directly as pollinating agents or honey gatherers. Nos. 411 and 412 are good examples of the fact that small packages can not be used at all seasons and under all conditions. The one had 5,044 bees and the other 7,754 on arrival, yet No. 411 succumbed to rigors of weather and the development of No. 412 was much reduced under the same conditions. The splendid record of No. 471, which began with 2,199 bees and increased its population slightly more than thirteenfold in 12 weeks, may be attributed in part to the good weather under which it developed.

Any apparent advantage of a small package over a large one, if received in favorable weather and with sufficient time to build up, seems due to the fact that under normal conditions the larger package reaches the normal seasonal level of colony population quicker. Consequently, if received too early, it can only drift with seasonal factors after building up, and so, among other things, it may even get the swarming impulse. The smaller package, however, has a longer road to travel in building up, and hence, if it succeeds in doing this, its record may look more impressive than that of the larger package installed at the same time.

ACTUAL LENGTH OF TIME NECESSARY FOR BUILDING UP

Regardless of the size of the original package, it is of the utmost importance that a package colony should build up quickly enough to avoid the danger of all the original bees disappearing before the colony is able to shift for itself. If the average period of life for the worker bee during the active season is 5 or 6 weeks, and if the bees in the package are young enough to average about 1 week in age, it is to be expected that some period after receipt of the package bees, but before about 5 weeks later, will be marked by the heaviest mortality among them. If this is the case it should be attended by a reduction in brood-rearing activity from the rate in the period immediately preceding and following. This would result in reduced emergence during a corresponding length of time three weeks later.

The emergence rates (Table 5) of the package colonies between the date of receipt and eight weeks later show such a break in 23 of 40 cases, beginning as early as the end of the fourth week in some colonies and not ending until during the eighth week in the case of others. These colonies were Nos. 402, 403, 404, 405, 411, 412, 413, 414, 421, 422, 423, 431, 432, 433, 434, 435, 441, 442, 443, 455, 473, 491, and 493. Fourteen of the remaining seventeen colonies (Nos. 415, 424, 444, 445, 451, 452, 453, 454, 463, 472, 475, 492, 494, and 495) showed within eight weeks from installation a period marked by slight or comparatively slight increase in the rate of emergence. After the break the rate of emergence rose to a level much higher in most cases than it had attained before. Even in Merrill's colonies an apparently similar condition is found.

By the end of five or six weeks after being installed, 26 of the 35 colonies used in 1927, whose original package population was determined, had reared enough new bees to equal this population.

(Table 12.) Deducting three weeks, the time during which no bees emerged after the package was installed, gives a period of from two to three weeks during which the emergence was sufficient to equal the original package population. During the next two weeks, in all cases except one, the increase in population likewise at least equalled the population in the packages originally. In several instances this occurred within one week. As a matter of fact, the computations show that at the end of the eighth week 13 of the 26 colonies had populations in new bees which were more than 3 times as large as those in their corresponding packages, while 6 of the 13 had reared enough new bees to make populations 4 to 5 times as large. After tracing the development of the packages this far, it becomes difficult to make generalizations as to the subsequent rate of increase which will fit the majority of the package colonies.

TABLE 12.—*Ratio between population* [1] *of package colonies for successive weeks and the population of the respective packages on arrival, 1927*

Colony No.	Computed number of bees in package	Ratio of population of colony (at end of number of weeks specified) to original population of package								
		4	5	6	7	8	9	10	11	12
471	2,199	0.58	1.27	2.17	3.61	5.63	7.57	9.76	11.73	13.11
431	3,175	.69	1.24	1.74	2.83	4.58	6.11	8.4		
421	3,952	.25	1.13	1.77	2.5	4.0	5.62	6.76	8.21	
411	5,044	.016	.062	.18	.25	.27				
452	5,622	.67	1.56	2.54	3.58	4.84	5.54	6.16	6.68	7.14
451	5,831	.57	1.53	2.57	3.69	5.22	6.13	6.58	7.04	7.45
491	6,413	.62	1.15	1.79	2.59	3.63	4.12	4.59	5.03	5.38
432	6,519	.66	1.16	1.51	2.27	3.69	4.56	5.75		
442	6,573	.41	.76	1.08	1.79	2.75	3.49	4.34	5.34	6.21
441	6,680	.44	.87	1.32	2.02	2.91	3.61	4.33	5.08	5.74
435	7,294	.67	1.24	1.73	2.58	3.46	3.74	4.25		
412	7,754	.017	.056	.16	.23	.27	.3	.28	.32	.41
422	8,129	.16	.75	1.39	2.04	2.66	3.36	3.58	3.75	
434	8,638	.6	1.12	1.56	2.23	3.28	3.78	4.42		
492	8,937	.31	.82	1.35	1.88	2.53	2.89	2.94	2.94	2.9
472	9,338	.61	1.34	2.12	2.96	3.95	4.46	4.94	5.3	5.5
423	10,021	.02	.43	.93	1.4	1.85	2.47	2.79	3.11	
443	10,120	.41	.83	1.26	1.93	2.74	3.23	3.7	4.18	4.43
473	10,147	.53	1.27	1.99	2.68	3.58	4.12	4.52	4.82	5.02
453	10,300	.58	1.4	2.26	3.15	4.18	4.67	4.96	5.08	5.14
433	10,715	.46	.86	1.2	1.72	2.61	3.07	3.65		
463	10,755	.36	1.021	1.7	2.41	3.23	3.76	4.07	4.34	4.46
493	10,918	.29	.81	1.33	1.88	2.52	2.86	2.74	2.64	2.56
445	11,365	.37	.82	1.27	1.75	2.28	2.46	2.52	2.56	2.55
413	11,985	.13	.38	.77	1.09	1.44	1.91	2.31	2.7	3.18
425	13,066	.17	.61	1.14	1.74	2.3				
444	13,629		.28	.68	1.09	1.62	2.22	2.47	2.59	2.69
475	14,527	.43	.96	1.52	2.09	2.76	3.04	3.11	3.07	2.88
414	14,585	.07	.29	.64	.93	1.24	1.74	2.2	2.55	2.97
454	14,671	.24	.66	1.10	1.58	2.22	2.63	2.87	3.11	3.32
424	14,836	.04	.32	.63	.99	1.34	1.65	1.79	1.92	
495	16,603	.12	.35	.68	1.17	1.69	2.08	2.27	2.36	2.29
415	17,229	.12	.37	.76	1.16	1.6	1.99	2.21	2.34	2.46
494	18,928	.31	.68	1.06	1.44	1.87	2.01	2.01	2.	1.96
455	19,376	.34	.81	1.25	1.69	2.16	2.24	2.12	2.02	1.9

[1] Only bees reared after installing the packages are considered in the computations.

In the two cases in 1926 in which the population in the eleventh week was computed, a slight increase was evidently still in progress even then. Of 29 package colonies investigated in their twelfth week in 1927, 24 attained their maximum population in this week. Three of this number belonged to lot 1, and so their original package populations were undetermined, but 9 of the remaining 17 belonged to the group having populations of more than 10,021 on arrival.

The points just discussed are of special interest and importance since, coupled with the fact that none of the packages studied for 10 or more weeks reached its maximum population (Table 10, figs. 4–6) before the ninth week, they would seem to indicate that packages should be installed at least eight to nine weeks in advance of the main honey flow if they are expected not only to replace themselves but also to reach approximately their maximum strength before the nectar flow is on.

In general, the smaller the package, the longer the time it requires to build up; but no package should be bought earlier than the time required to fulfill the purpose for which it is bought, whether this be for it to build up in time for a honey flow or for its bees to serve directly as pollinating agents. If packages are obtained too early, the beekeeper may be rushed for time when they arrive, he may pay a

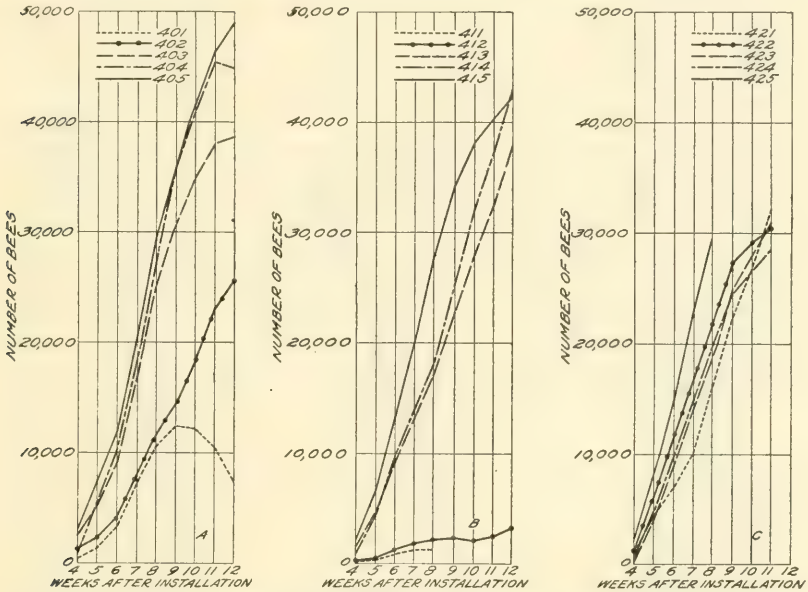

FIGURE 4.—Computed worker populations in package colonies in successive weeks after installation: A, Colonies Nos. 401, 402, 403, 404, and 405; B, colonies Nos. 411, 412, 413, 414, and 415; C, colonies Nos. 421, 422, 423, 424, and 425

price higher than he would pay later in the season, in certain regions he may run the risk of losing the bees in unseasonable weather during shipment or after arrival, or he may even run the risk of having them build up to maximum strength so soon that they will get the swarming fever before the main honey flow is on. Needless to say, obtaining packages too late may also mean wasted time and money on the part of the purchaser. The beekeeper must know his region, its weather, its honey flows, and its pollen yields. He can then pick the right size of package and install it at that time of the year which will give him the biggest return for the time and money spent.

That the foregoing conclusions on the time required for packages to build up and on the merits of different sizes of packages are borne out in apiary practice seems evident from the two following quotations. L. T. Floyd, provincial apiarist of Manitoba, speaks in favor of 2-

pound packages for Manitoba, a region providing 12 weeks in which packages can build up for the main honey flow. He says (*7*):

> When a two-pound package of bees delivered on May 1 will, in a good season, build up and gather a 200-pound crop of honey it should satisfy any one. Bees are able to do this in Manitoba because the crop comes in August and September. If larger packages are used, swarming becomes a problem.

Demuth (*6*), on the other hand, in summing up for the United States, in which are many localities where main honey flows come at times which afford much less than 12 weeks for colonies to build up, says:

> Experience of those who have purchased many packages of bees would indicate that the three-pound package is large enough for the capacity of the ordinary

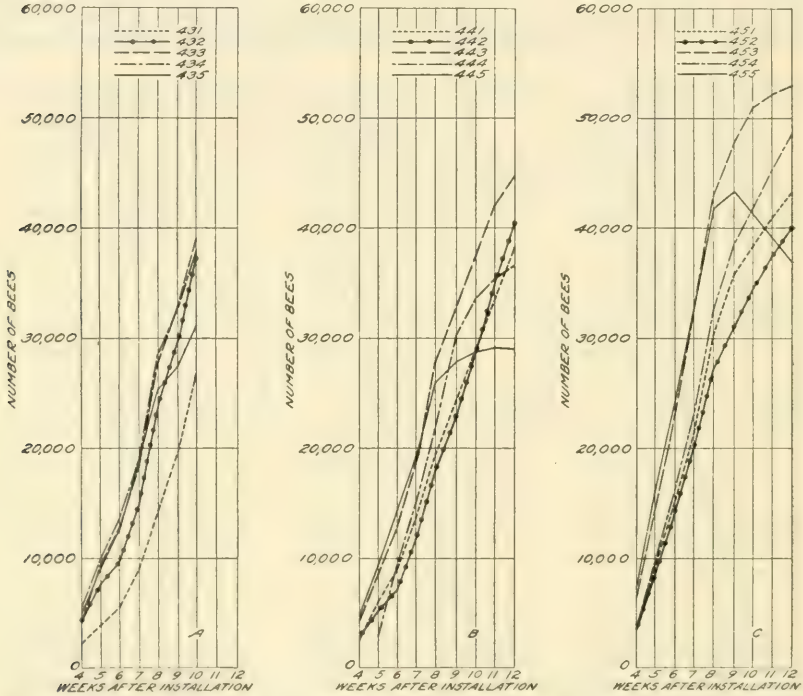

FIGURE 5.—Computed worker populations in package colonies in successive weeks after installation: A, Colonies Nos. 431, 432, 433, 434, and 435; B, colonies Nos. 441, 442, 443, 444, and 445; C, colonies Nos. 451, 452, 453, 454, and 455

queen, provided there are about eight weeks for building up for the honey flow. Many have found the two-pound package to be more profitable than the three-pound package.

IMPORTANCE OF BEES OF PROPER AGE

In this experiment no attempt was made to get bees of any particular age other than the effort to secure bees uniform in condition. In view of the division of labor among bees it is apparent that if the packages are to be used for developing into new colonies the bees should be young enough to engage actively in brood-rearing activities. The same thing is true if they are to aid weakened colonies. If the bees in the package are to be used directly as honey gatherers or pollen gatherers, then on arrival they should be of the proper age

physiologically for these tasks. Practical methods for filling the packages with bees of the desired age remain to be worked out.

LENGTH OF TIME ON ROAD

Since the length of a bee's life depends upon how much work it accomplishes, the less time spent in shipment, the better for the package colony, whether the bees are young or old. According to the investigations of Rösch (*37*) and Soudek (*39*), a deterioration of the pharyngeal glands probably is taking place at all times, and a few extra days on the road under conditions tending to age the bees physiologically would mean that the workers would be proportionately less able to feed young larvae. On the other hand, since at least three

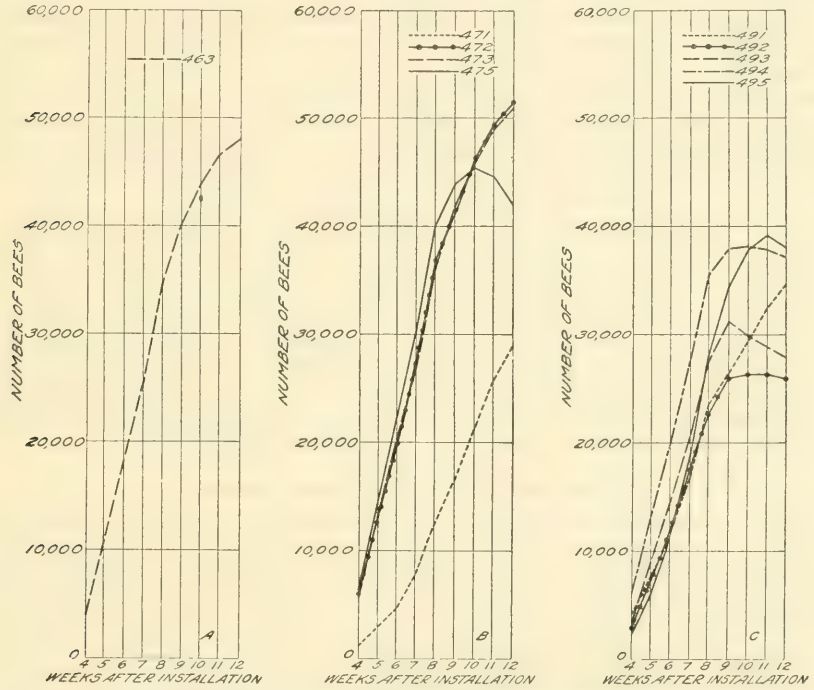

FIGURE 6.—Computed worker populations in package colonies in successive weeks after installation: A, Colony No. 463; B, colonies Nos. 471, 472, 473, and 475; C, colonies Nos. 491, 492, 493, 494, and 495

weeks must elapse after the package is installed before new recruits will be added to the colony by brood rearing, it is highly essential to have the package bees at work as soon as possible in order to rear the largest possible number of new bees before the original package bees die off.

There is practically no region in the continental United States in which an express package can not be received within two or three days from a region producing package bees. Consequently, since the bees in this experiment were on the road at least two days, it is felt that fairly normal conditions were obtained so far as the length of time in transit is concerned. These bees, furthermore, were shipped in weather varying from freezing to midsummer temperatures. Although, other things being equal, it is quite obvious that bees

should be bought from the point which involves the shortest time on the road, this is not always done. For instance, it is said that shipments to some points in Canada are on the road for a week (*8*). Under normal conditions such a length of time scarcely seems necessary in the United States if the packages are bought from the nearest producing center. If it is necessary, special attention should be paid to the conditions under which the packages are shipped. The use of refrigerator cars for this purpose would seem to offer a fruitful field of investigation.

EFFECT OF WEATHER CONDITIONS AT TIME OF INSTALLATION

The most noticeable consequence of unseasonable weather during the experiment in 1927 was the loss of package colony No. 411, which, when received, was not large enough to resist the cold. The development of No. 412 was likewise interfered with. On other occasions, because of cold weather, the bees did not leave their shipping cages readily during the night following installation and had to be shaken out when the cages were removed the following morning. This happened principally in lot 2, package 422 of lot 3, and in lot 7. A handful of bees were still lingering the next morning in the cages of lots 1 and 4, and in the remaining packages of lot 3.

Cold weather at the time of installation also retarded the taking of sirup freely by lots 2 and 3. The two larger colonies in each lot lowered the sirup only one-half inch in the jar on the day after installation; the other colonies took scarcely any sirup. Lot 1 took sirup freely on the first day because the weather was somewhat warmer.

Cold weather or cool and rainy weather checked flights for the first day or two after arrival in the case of lots 2, 3, 4, and 7. Weather conditions were so favorable on the days of installing lots 5, 8, 9, and 10, however, that those lots had good flights before night.

USE OF SIRUP WHEN INSTALLING PACKAGES

All the package colonies used in 1927 began to take sirup from the feeders to a greater or less extent within 24 hours after being installed, depending somewhat upon the temperature but to a certain extent apparently regardless of current nectar flows. It is to be remembered that the bees were hived upon combs which were empty except for the cupful of sirup in one of them. The bees in the first lot took more sirup within 24 hours after installation than did those of any other lot. This was to be expected in view of the fact that little, if any, nectar was available from the field so early in the year. The bees in some of the succeeding packages were evidently deterred by prevailing low temperatures from taking sirup during the first 24 hours. Lot No. 10, however, which arrived during the tuliptree nectar flow and under favorable temperature conditions, took sirup readily even within a few hours after installation.

As a matter of fact, the bees in the three largest packages of lots 1 and 10, the first and the last lot, began to take sirup more readily than those in the packages of any of the other lots. Those in Nos. 403 and 405 emptied the 2-quart jar of sirup within 24 hours of installation, being the only packages to do so, while colonies 402, 404, 493, 494, and 495 required 24 hours longer for the purpose. The only other packages which emptied the 2-quart feeder within 48 hours of installation were Nos. 451, 472, 475, and 483. Eleven package

colonies (Nos. 401, 414, 415, 442, 444, 445, 453, 465, 473, 474, and 485) required three days. The bees in the remaining packages required from four to nine days to empty the jar.

It is evident from the data given on the brood-rearing activity of the package colonies that the leaders in this respect took sugar sirup actively on installation regardless, at least at first, of whether or not nectar was available in the field. It would seem that the work of the bee in using sirup from the feeder would cause it far less wear and tear than gathering nectar from the field. If this holds true, and if the bee could be kept from deserting the feeder for the field, the bee's energy would be conserved by giving sirup during this period, and a correspondingly greater number of new bees would be reared before the original package bees died off. Perhaps giving sirup to the package bees when installed is better than giving combs of honey. This would seem to be the case if the bees, which ordinarily would carry the sirup from the feeder, should engage in gathering nectar from the field in case combs of honey were substituted for the sirup. In the latter event it would seem that they would wear out sooner than if they had been carrying sirup from the feeder, although their activities under such conditions are not well known.

EFFECT OF PRESENCE OR ABSENCE OF A QUEEN BEE IN THE PACKAGE DURING SHIPMENT

It has been frequently stated in beekeeping circles that combless package bees ship better with queen bees than without queen bees. In this experiment the packages in lots 1, 2, 3, 9, and 10 were shipped without queen bees. Except for No. 402, none of these packages showed any greater rate of mortality than did those packages shipped with queen bees. In fact, the highest loss in any lot occurred in lot 5, of which all the packages contained caged queen bees. There appeared to be no particular difference in the promptness with which queen bees arriving caged in the packages and those shipped separately began to lay. In each case the bees immediately began to release the queen from the Miller cage, and acceptances were as many in one case as in the other. Of the two original queen bees not accepted when released, one (that in No. 404) had been given to a package which had been shipped queenless, while the other (that in No. 444) had accompanied the package in shipment from the producer. Of the other 24 queen bees in the group not shipped with the packages, all survived, and none was even balled, with the exception of the queen in No. 483, which was released in good shape but was balled on the third day when the hive was opened. Of the 25 queens which came with the packages, in addition to the 1 lost as already mentioned, 3 more were lost within nine days of the time of arrival, while 2 others were balled, but not fatally, soon after being released from their cages. Another proved incapacitated in some way. So far as this experiment is concerned, therefore, practically as good results were obtained by shipping the packages queenless as by shipping them with queens.

It may be added that all the queens shipped in the packages were in mailing cages which contained both candy and attendants. Only one of these queens (that in No. 475) was lost in shipment.

BALLING THE QUEEN BEE

It is only repeating an old axiom to mention that a colony in which a queen has been newly introduced should not be disturbed for several days. In this experiment, however, it was desired to get exact data on how soon the queen was released from the Miller cage and when she commenced egg laying. For this reason the colonies were examined each day after being installed until these facts were ascertained. In spite of every precaution four queens (those in 424, 454, 473, and 483) were found balled within two days after the packages were installed. They were thereupon rolled in honey, returned to their colonies, and three (those in 424, 454, and 473) were reaccepted. This treatment apparently did not save the fourth, since No. 483 was found queenless four days later. Two queen bees (those in 404 and 444) were lost within two days after being introduced, whether because of the premature opening of the hive or not. Three others (those in 461, 465, and 474) were lost within six to nine days after being introduced, although balling, if it occurred, was not observed.

IMPORTANCE OF TIME WHEN THE QUEEN BEE IS RELEASED

Needless to say, the quicker the queen begins to lay in the package colony the better. For purposes of building up, this becomes doubly important when the time between receipt of the package and the opening of the honey flow is limited, and also in case the bees in the package are just passing out of the nurse-bee stage. Since none of the queens used in this experiment came free in the package, each was introduced as described earlier. In 6 of the 35 colonies, into which the queen bees were introduced without use of the tin over the Miller cage, a few cells of sealed brood were found (Table 13) on the ninth day after the package was installed. The queens in one-half of these (Nos. 475, 492, and 494) had not been shipped in the packages. In 13 cases 10 days elapsed between installation and the occurrence of the first sealed brood; in 6 cases, 11 days; in 6 cases, 12 days; and in 2 cases, 13 days. In 5 of the remaining 6 colonies of this group, the original queen bees were lost during the first few days, while eggs were found in the sixth on the fifteenth day after the package was installed.

In 8 of the 15 package colonies whose queen bees were caged safely for one day while being introduced, sealed brood was found on the eleventh day after the queen was installed. In 2 instances this period was 12 days, while 16 days was the longest period for any of the remaining 5 queens.

TABLE 13.—*Number of days from time of installation of package to appearance of sealed brood*

Package No.	Days	Remarks
401	11	Queen caged safely one day.
402	11	Do.
403	11	Do.
404	15	This refers to the second queen. She was caged safely one day.
405	11	Queen caged safely one day.
411	15	Queen given one day after installing package. She was caged safely five hours.
412	12	Do.
413	12	Do.
414	13	Do.
415	11	Do.

TABLE 13.—*Number of days from time of installation of package to appearance of sealed brood*—Continued

Package No.	Days	Remarks
421	11	Queen caged safely one day.
422	11	Do.
423	16	Do.
424	14	Queen caged safely one day. She was balled once during the 14-day period.
425	11	Queen caged safely one day.
431	10	
432	10	
433	10	
434	10	
435	10	
441	9	
442	10	
443	10	
444	19	This refers to second queen.
445	10	
451	12	
452	10	
453	10	
454	13	Queen was balled once during this period.
455	9	
461		Queenless on ninth day.
462		Unsealed brood on fifteenth day.
463	10	
464	12	
465		Queenless on ninth day.
471	12	
472	9	
473	12	Queen was balled once during this period.
474		Queenless on sixth day.
475	9	
481	10	Queen given one day after installing package.
482	11	Do.
483		Queen given one day after installing package. Queenless on sixth day. The queen was balled once during this period.
484	11	Queen given one day after installing package.
485	10	Do.
491	12	
492	9	
493	13	
494	9	
495	12	

It is an open question whether the proportion of colonies in which sealed brood was found nine days after installing the package would have been materially increased if the queens had been shipped free in the packages. Even if this had been the case, it must be remembered that the sealed cells found on the ninth day after the packages were installed had been sealed only a few hours at most, while the majority of the sealed cells found on the tenth day, which marks the end of the first 24 hours of sealing, arose from eggs laid within 24 hours after the packages were installed. It is readily apparent that in all such instances the workers in less than 24 hours ate through the candy imprisoning the queen in the Miller cage and that the queen began laying within a few hours at the most.

IMPORTANCE OF A PROLIFIC QUEEN BEE

Thirteen of the 40 queens in the colonies whose sealed brood was counted in 1927 had daily effective egg-laying averages of over 1,400. Three of these were in excess of 1,600, the highest being 1,646. All 3 of the queens used in the experiments in 1926 attained daily effective egg-laying averages in excess of 1,400 but below 1,599. Of the remaining 27 queens used in 1927, 11 attained over 1,200 for this rate but below 1,399, while 7 had rates between 1,000 and 1,199. Six were between 883 and 987.

Three queens, those in colonies 401, 411, and 412, had daily average rates below 600. Their low rates are to be explained by the fact that the queen in No. 401 soon proved to be a drone layer, while the queens in Nos. 411 and 412 arrived during such inclement weather and with so few bees in comparison with the other colonies of this lot that they were handicapped by the unfavorable conditions.

The data on the effective egg-laying rates, taken in connection with the computed number of bees originally in the packages, give some interesting facts. Apparently there was considerable variation in the prolificness of the queens, since the highest egg-laying rate was not found in the colony which developed from the package with the largest number of bees. For instance, No. 473, the colony whose queen had the maximum daily effective egg-laying average, 1,646, had only 10,147 bees on arrival, whereas the queen of the largest package, No. 455, which contained 19,376 bees, had a maximum daily effective rate of only 1,300. This rate was attained early, however. No. 432 had only 6,519 bees in its original package, but its queen attained a rate of 1,566 before the end of the experiment, whereas No. 424 had 14,836 bees, but its queen subsequently attained a daily effective rate of only 947.

It must be remembered that the data just given on effective egg-laying rates represent only the maxima and cover only a few days. Nevertheless, they indicate differences in the individual queen bees.

It is quite evident that the package whose queen soonest attains a satisfactory effective average will be apt to maintain an advantage in population over other colonies during the first few weeks. Thus, 7 of the 40 queens used throughout the experiment attained an effective daily egg-laying average of over 1,000 within 30 days after the packages were installed. These were: The queen in No. 473, which attained an average of 1,075 by the twenty-fourth day; the queens in Nos. 453 and 455, which attained 1,204 and 1,300, respectively, on the twenty-seventh day; the queen in No. 494, which reached 1,008 on the twenty-eighth day; the queen in No. 463, which reached 1,011 on the twenty-ninth day; and those in Nos. 472 and 475, which showed averages of 1,001 and 1,144, respectively, on the thirtieth day. It is to be noted (Table 10) that none of the other package colonies surpassed any of these seven in the computed total number of new bees on hand in each until the ninth week after installation. That a prolific queen can, to a certain extent, overcome a handicap in regard to number of workers in her colony is shown in these seven packages also, since Nos. 453 and 455 arrived with 10,300 and 19,376 bees, respectively, but on the twenty-seventh day the effective egg-laying averages of the queen in each showed a difference of only about 7 per cent.

PACKAGE BEES AS POLLENIZERS

The observations made as to the time when pollen gatherers were first seen in the different package colonies is of interest in connection with the use of package bees as pollenizers and in determining how long in advance of blossoming they should be obtained. As stated before, most of the packages were received after 4 p. m. and were installed before dark. In the case of 21 packages (Nos. 401, 402, 403, 404, 405, 451, 452, 453, 454, 455, 475, 481, 482, 483, 484, 485, 491, 492, 493, 494, and 495), bees were observed coming in with pollen within

one day after they had been received. In most of these cases the pollen gatherers were observed between 8.30 and 9 a. m. Both the smaller and larger packages were represented. Weather conditions undoubtedly prevented the gathering of pollen so soon by the colonies in some of the other lots. It is of special interest that in colony 494, belonging to a lot hived at noon, pollen gatherers were observed returning at 4 p. m. This experiment shows that bees from packages may begin to gather pollen within a few hours after being installed. Since the period for pollinating any plant is relatively short, such behavior on the part of the bees is of particular value because it makes feasible the procuring of packages just at pollinating time merely for pollinating purposes without any idea of having the bees build up into colonies.[5]

PACKAGE BEES AS HONEY GATHERERS

Although most of the 3-pound packages were placed on scales, unfortunately none received at the time of the main honey flow was thus treated, package No. 473, received on May 4, being the last to be put on scales. The main honey flow was on by May 20, by which time the bees in No. 473 had already been at work over two weeks. The first brood in this colony was sealed on May 17, which means that no young bees emerged before May 26. Nevertheless, this colony gained 0.66 pound during the daytime on May 21, 0.79 pound on May 22, 0.86 pound on May 23, and 0.7 pound on May 24. It would have been of particular interest to test the performance of the lot received on May 11 and more particularly the performance of the lot installed on May 19. Even colony No. 463, however, furnishes a little evidence on this question, since it was received on April 27 and its first new bees were not out before May 16. It is rather doubtful that many, if any, of these were flying five days later, May 21, on which date the colony gained 0.55 pound during the daytime. On May 22 the daytime gain was 0.86 pound, on May 23 it was 1.32 pounds, and on May 24 1.54 pounds. Possibly at this time young bees were also flying.

Although these gains are slight even in comparison with those of colony No. 403, which on several days in May brought in over 7 pounds of nectar, the highest amount, 9.5 pounds, being on May 23, it must be recalled that these package colonies were rearing brood as well as gathering nectar and pollen. They had been working for over two weeks after being installed, with no help from newly emerged bees in No. 463, and with scant, if any, help from the few bees newly emerged by this time in No. 473. Consequently it is reasonable to suppose that package bees, especially those of field age, if added to a weak colony at the time of the honey flow, would prove of immediate value in gathering honey.

It is interesting to compare the amount of nectar which the computed field force of some of the colonies described here might have gathered with what other typical package colonies are reported actually to have gathered in the sweetclover region. Colony No. 301 will show this as well as any. Munro [6] has stated that a package received on June 3, 1926, at the apiary of the North Dakota Agricultural Experiment Station showed a gain of 268 pounds from July 21 to September 17. In a private communication he furnished the

[5] See footnote 4.

[6] Munro, J. A. N. Dak. Beekeepers' Assoc. News Letter, v. 4, no. 1, October, 1926. [Mimeographed.]

additional information that the package had contained 3 pounds of bees and that sweetclover in his region in 1926 was in blossom from about the middle of June until the middle of September. This means that the package was received approximately two weeks before the beginning of the main honey flow. By July 21 the colony had gathered about 50 pounds. Its highest 24-hour gain, 18¼ pounds, came on July 31, a little more than eight weeks after the package was installed. Its highest 24-hour gain during the next month was 15 pounds, on August 12, ten weeks after being received, while on September 6 it made a gain of 10¾ pounds.

From computations based on counts of its sealed brood, colony No. 301 (Table 14) should have had approximately 21,000 field bees on hand at the end of eight weeks after being received, if we follow Rösch's results previously cited. This figure was barely exceeded during the remaining weeks of the observations. If worker bees on an average go to the field younger than at the age given by Rösch, or if their average length of life is longer, the number of bees given here would be too small, at least during some of the succeeding weeks. Thus, assuming a duration of life of six weeks, of which the last three weeks are devoted to field duties, about 28,000 field bees were on hand by the end of the ninth week of the observations.

Assuming that each bee makes 10 trips per day to the field for nectar, as is well warranted both by Park's work (*29, p. 132; 30, p. 213*) and by that of Himmer (*13, p. 146*), and assuming further that each bee carries in one-fourth of its own weight in nectar on each trip, but that, according to Hambleton (*12*), one-fourth of this nectar is evaporated off as water overnight, a field force of 21,000 could be expected to make a daily gain of 7⅞ pounds during the honey flow. A field force of 28,000 could give a result of nearly 10 pounds daily. Both of these calculations are based on the assumption of 5,000 worker bees to the pound.

TABLE 14.—*Population of worker bees in colony No. 301 reared after hiving package on April 23, 1926, as calculated from computed emergence rates*

Date	Number of weeks after hiving package	Computed number of worker bees in the colony, assuming a 5-week average period of life and a division of duties according to Rösch				
		Cell cleaners, 0–2 days	Nurse bees, 3–10 days	Intermediate bees, 11–19 days	Field bees, 20–35 days	Total
Apr. 30	1	0	0	0	0	0
May 7	2	0	0	0	0	0
May 14	3	0	0	0	0	0
May 21	4	2,888	6,859	0	0	9,747
May 28	5	2,272	11,207	5,144	0	18,623
June 4	6	2,739	9,789	13,500	1,715	27,743
June 11	7	2,709	10,778	10,999	12,635	37,118
June 18	8	2,794	11,000	12,208	20,895	46,897
June 25	9	2,713	11,050	12,223	20,739	46,726
July 2	10	2,889	11,040	12,491	21,289	47,719

It should be borne in mind, however, that the days in the sweetclover region of the North are long and that the season of the sweetclover honey flow itself in that region is relatively long, being between two and three months.

In certain western arid regions the nocturnal loss in weight of nectar by evaporation is even less than that used in the foregoing calculations. Furthermore, according to Gillette *(11)* and Park (*29, p. 133*), bees usually carry loads equal to about one-half or even more of their own body weight, while Park (*29, p. 132*) found bees under optimum conditions making 20 trips or more daily. If optimum conditions recorded by various investigators are assumed, the field force of 21,000, computed for colony 301, could account for much more than a daily gain of 20 pounds, and under sweetclover conditions would, theoretically, at least, be capable of equalling the large honey crops mentioned earlier in this bulletin. It is felt, for this reason, that this colony and the others were fairly typical package colonies in their development, especially since larger field forces were attained in others of the package colonies before the end of the experiment.

SUMMARY

Some of the results of the experiment may be briefly summarized as follows:

The actual live weight of bees in individual packages when received bore little relation to the weight billed by the shipper. As a rule the smaller packages weighed more and the larger packages less than the billed weight.

In no case did the bees average 5,000 bees to the pound. If the latter figure holds for empty bees, the individual weights of the bees in these packages as determined on their arrival may be taken to indicate that, on an average, they were holding approximately half their weight in sirup.

In the colder weather the larger packages showed to advantage. The larger packages also built up to normal colony strength quicker. Over a sufficiently long period, on the other hand, the smaller packages showed a higher relative increase.

Packages should be allowed eight to nine weeks in which to build up, and, if small, even more.

Under good conditions package bees can easily stand at least two or three days' shipment.

Package bees in this experiment made use of a feeder in the hive even when a nectar flow was on in the field.

In this experiment no particular difference could be detected in the condition on arrival of those packages shipped with queen bees and those shipped without them. Nor was there any difference in the time elapsing before the queen bees in the two cases began to lay.

In the experiment, regardless of the known risk of having the queen bees balled, it was necessary to examine the colonies daily after they had been installed. Of the 50 queen bees, 4 were found balled within two days after the bees had been installed. Three of these queens were reaccepted after being rolled in honey. Two other queen bees were lost within two days, and three within six to nine days after the packages had been installed, but it was not ascertained in these cases whether the queen had been balled.

Over half the queen bees commenced laying within 24 to 48 hours after the bees had been given access to the candy in the queen cage. Such access in the majority of these cases was given immediately at the time of installing the packages.

A prolific queen is highly essential for the optimum development of the package.

The proper age for bees in the package depends on the use to which they are to be put. If the packages are to develop into colonies or are to help weaker colonies develop, the bees should be young enough physiologically to engage actively in brood-rearing activities. If the bees are to be used directly as pollenizers or nectar gatherers, they should be just entering field age. In any case they should be young enough physiologically to insure their proper functioning in the desired activity.

Under proper conditions bees from packages will gather pollen within a few hours after being installed. This fact makes possible the use of the original bees in the package as pollenizers without the necessity of having them build up into colonies.

The original bees in certain of the packages gathered nectar. This at least indicates the feasibility of securing a larger honey crop by reinforcing weakened colonies just before the honey flow with bees of the proper physiological ages both to gather and to store nectar.

A package colony with even 21,000 field bees, under the optimum conditions prevailing in certain localities and with long seasons for nectar gathering, can store a satisfactory quantity of honey.

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BIOLOGY OF SOME JAPANESE AND CHOSENESE GRUB PARASITES (SCOLIIDAE)

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CONTENTS

	Page		Page
Introduction	1	Oviposition—Continued.	
Host relationships	2	Number of eggs	14
The life cycle	4	Host mortality through mechanical injury	15
Number of generations	4	The immature stages	16
Length of the egg stage	5	The egg	16
Length of the larval stage	6	The larva	17
Time passed in the cocoon	7	The cocoon	19
Length of adult life	7	Parthenogenesis	21
Feeding habits of adults	8	Natural enemies	21
Oviposition	10	Summary	24
Paralysis of the host	10	Literature cited	25
Manner of oviposition	10		
Position of the egg	12		

INTRODUCTION

In the course of the investigations upon the natural enemies of the Japanese beetle (*Popillia japonica* Newm.) in the Far East during the period from 1920 to 1928, inclusive, occasion arose to study the habits of a considerable number of species of Scoliidae parasitic upon the grubs of this and other Scarabaeidae, representing the subfamilies Rutelinae and Melolonthinae. For comparative purposes only those from Japan and Chosen (Korea) are dealt with in this bulletin, though occasional notes are given upon certain Chinese and Indian species. Among those treated the genera Scolia and Campsomeris are represented by a single species each, and the remaining 15 species are of the genus Tiphia. Several of the Japanese and Chosenese species occur also in China and were studied there by H. A. Jaynes from 1924 to 1926, inclusive.

The taxonomic determinations of all the species of Tiphia dealt with herein, with the exception of three previously described by S. A. Rohwer, have been made by H. W. Allen and H. A. Jaynes. Their recent publication (*1*)[1] deals with practically all the species encountered in the investigations in Japan, Chosen, China, and

[1] Italic numbers in parentheses refer to Literature Cited, p. 25.

India, and the greater proportion of them have been described as new in the article cited.

The principal points dealt with in this comparative study are the host relationships, the life cycle, the food habits of the adults, the position and manner of placement of the egg upon the host body, and the type of cocoon. Notes are also given upon such of the natural enemies of the family as have been encountered.

HOST RELATIONSHIPS

All the scoliid species studied have been found to be parasitic upon scarabaeid grubs of the subfamilies Melolonthinae and Rutelinae. In the list below are given the species and their recorded hosts. The records on some of these host species are based on field observations and thus represent the normal host relationship of the parasites, whereas the records on the remaining grub species are from insectary experiments and indicate suitability for development only, with the possibility that some may properly belong to the first group.

Species	Hosts
Scolia japonica Smith	*Anomala sieversi* Heyd.[2]
Campsomeris annulata Fab	*Phyllophaga diomphalia* Bates.[2] *Anomala* sp.[2] *Popillia* spp.
Tiphia agilis Smith	*Serica orientalis* Mots.[2] *Serica* sp.
Tiphia asericae A. and J	*Serica* spp.[2]
Tiphia bicarinata Cam	*Anomala sieversi* Heyd.[2] *Phyllopertha pubicollis* Waterh.
Tiphia biseculata A. and J	*Anomala* sp.[2]
Tiphia brevilineata A. and J	*Anomala sieversi* Heyd.[2] *Phyllopertha pubicollis* Waterh.[2] *Popillia mutans* Newman.
Tiphia korcana Roh	*Anomala sieversi* Heyd.[2] *Popillia atrocoerulea* Bates. *Phyllopertha pubicollis* Waterh.
Tiphia malayana Cam	*Serica* spp.[2]
Tiphia notopolita alleni Roberts (*11*)	*Phyllopertha conspurcata* Har.[2] *Phyllopertha pallidipennis* Reitt.
Tiphia ovidorsalis A. and J	*Serica* sp.[2]
Tiphia ovinigris A. and J	*Phyllophaga* sp.[2]
Tiphia phyllophagae A. and J	*Phyllophaga diomphalia* Bates.[2] *Phyllophaga* sp.[2]
Tiphia popilliavora Roh	*Popillia japonica* Newman.[2] (Japan.) *Popillia atrocoerulea* Bates.[2] (Chosen.) *Popillia castanoptera* Hope.[2] (Chosen.) *Popillia formosana* Arrow.[2] (China.) *Phyllopertha* sp.
Tiphia tegitiplaga A. and J	*Anomala* sp.[2]
Tiphia totopunctata A. and J	*Anomala sieversi* Heyd.[2] *Phyllopertha pubicollis* Waterh.
Tiphia vernalis Roh	*Popillia castanoptera* Hope.[2] *Anomala* sp. *Phyllopertha* sp.

[2] From field observation.

In view of the wide distribution of *Scolia japonica* (fig. 1), as compared with that of its known host, it is evident that other species, and possibly other genera as well, are attacked in addition to *Anomala sieversi*, of which there is a single record. The larger Scoliidae, represented by Scolia and Campsomeris, appear to be more general in their choice of hosts than is Tiphia. *Campsomeris annulata* (fig. 2), of wide distribution throughout the Far East, is found in Chosen parasitic upon *Phyllophaga diomphalia* and *Anomala* sp. and will develop very readily upon *Popillia* spp. under laboratory conditions; in fact, it has occasionally been found upon this genus in the field.

In the genus *Tiphia* the number of species with known host records is sufficiently great to permit of some conclusion being drawn regarding the general host relationships of the group. It may be stated that the species of Tiphia are, in general, generic rather than specific in their choice of hosts. Specificity in this respect has been

FIGURE 1.—*Scolia japonica*, female. × 2.7

claimed for many species, but investigations indicate that this is only regional and not absolute. Thus *Tiphia popilliavora* (fig. 3) is specific upon *Popillia japonica* in northern Japan, owing primarily to the lack of other representatives of the host genus in that country. The parasite, however, occurs in Chosen and China, whereas *P. japonica* does not occur on the Asiatic mainland, where the hosts are *P. castanoptera*, *P. atrocoerulea*, *P. formosana*, and other members of the genus. In any given locality it confines itself almost exclusively to a single host species, even though others of apparently equal suitability are present. *T. popilliavora* will develop quite readily upon Phyllopertha grubs under laboratory conditions.

It is rather noteworthy that a considerable number of species of Tiphia will oviposit and develop readily upon Phyllopertha grubs in the laboratory. Practically every species tested in this respect, which had as its normal host either Anomala or Popillia, would

transfer and develop readily on grubs of this genus. In contrast to this was the reaction of the several Phyllophaga parasites of this genus under similar conditions. From the very few eggs that these species were induced to deposit on grubs of other genera not a single larva developed beyond the primary stage.

The stage of development at which the host larva is attacked is of importance from the point of view of parasite development and increase. Scolia and Campsomeris confine themselves quite strictly to the final larval stage of the host, but this does not hold true in the case of many species of Tiphia. It has been noted that several species parasitic upon Phyllophaga normally attack the intermediate rather than the final stage, and this has been observed in the case of *T. notopolita alleni*. *T. popilliavora* in northern Japan also oviposits indiscriminately upon the last two host stages. At the time when the adults of this species are in the field (the middle of August

FIGURE 2.—*Campsomeris annulata*, female. × 3.5

to the middle of September) in northern Japan the host is represented by two generations of grubs in the soil, this condition being due to a partial 2-year cycle. Thus, both fully mature grubs from eggs of the preceding season and first and second stage ones of the current generation are found in good numbers. Both the mature forms and those of the early second stage are attacked, apparently without any marked preference being shown between them. The cocoons resulting from development on the very small, immature grubs are often less than 3 mm. in length, much resembling an average sized Apanteles cocoon, and a great proportion of them never yield adult wasps.

THE LIFE CYCLE

NUMBER OF GENERATIONS

The life cycles of the Scoliidae are markedly affected by climatic conditions—far more so in fact than are those of many other para-

sitic groups. In the Tropics, unless activity is inhibited during a portion of the year by high temperatures and exceptionally low humidity, resulting in a period of aestivation, breeding goes on continuously throughout the year, and from three to six generations may be produced. In countries in the Temperate Zone, such as Japan and Chosen, this number is considerably reduced. Here *Scolia japonica* has, questionably, a single generation each year, while *Campsomeris annulata* has two, and possibly three. Of the 15 species of Tiphia listed herein, 11 have a single generation each year, while *bisceulata* and *tegitiplaga* have two. This latter case is due to their occurring in a locality having an exceptionally short and mild winter and a very sandy soil, the latter factor being responsible

FIGURE 3.—*Tiphia popilliavora*, female. × 7.3

for an earlier emergence in the spring and longer-continued growth in the fall than is the case in heavy soils. *T. ovinigris* and *T. phyllophagae*, both parasitic upon Phyllophaga grubs, apparently have a 2-year cycle to accommodate themselves to a corresponding cycle in the host.

LENGTH OF THE EGG STAGE

Within the family the duration of the egg stage ranges from 1 to 6 days under optimum summer conditions, with Tiphia in general having a longer incubation period than Scolia or Campsomeris. The above period may be extended to 10 or 15 days in the case of Tiphia breeding under lower temperature conditions. In the insectary breeding work with the species occurring in late fall it was found

that development was almost entirely inhibited, and consequently it was necessary to provide heating facilities to raise the temperature sufficiently to bring them to hatching and to carry on the development to the maturity of the larva.

The minimum period of incubation of *Scolia japonica* was found to be 1 day and that of *Campsomeris annulata* 2½ days. Of the species of Tiphia ovipositing in May the eggs of *vernalis* hatched in 13 days (7 days in June) and of *malayana* in 10 to 11 days. In June, July, and August, the period of maximum temperatures and high humidity, the time of hatching ranged from 3 days in the case of *asericae* and *bicarinata*, and 3 to 4 days in *agilis*, *brevilineata*, and *ovidorsalis* to 5 or 6 days with *totopunctata*. Eggs of *T. biseculata* required 4 days in the spring generation (June) and 5 days in the fall brood (September). The eggs of *T. popilliavora* hatched in 3 days at Suigen, Chosen, in late August, in 5 days at Yokohama in the same month, in 8 to 11 days in northern Japan in late August and September, and, as a maximum, in 10 to 14 days in Chosen during early October. Of the remaining fall species *notopolita alleni* required 4 or 5 days in September, *phyllophagae* and *ovinigris* 5 or 6 days in the same month, and *tegitiplaga* 7 days in the latter part of that month. Eggs from late emerging *T. koreana* females also required 5 to 6 days for incubation in September. It is thus seen that there is a considerable uniformity among the different species occurring at the various seasons of the year, and that the longer incubation recorded for many species is attributable directly to temperature influences rather than being a constant species characteristic. This point is brought out particularly well in the case of *T. popilliavora* in the various localities in which it is found, the duration of the stage ranging from 3 to 14 days, due solely to variations in temperature.

LENGTH OF THE LARVAL STAGE

The variation in the duration of the active larval stage, from the time of hatching to the formation of the cocoon, is similar in extent to that found in the incubation period. In *Scolia japonica* and *Campsomeris annulata* this stage is very short, covering only 4 days for the former and 5 days for the latter species under optimum summer conditions. Among Tiphia, *vernalis* and *malayana* require 20 to 25 and 21 to 22 days, respectively, at the end of May, under the relatively high temperatures then prevailing. In June, July, and August *asericae* larvae matured in 10 to 12 days, *ovidorsalis* in 11 to 14 days, *agilis* in 12 to 13 days, *biseculata* in 18 days in June (30 in late September), *brevilineata* in 12 to 15 days, *totopunctata* in 18 to 20 days, *bicarinata* in 12 to 20 days (late August and early September), and *koreana* in 18 to 20 days. Of those developing in September *notopolita alleni* required 15 to 17 days (18 to 19 in early October), *phyllophagae* 17 to 21 days, *ovinigris* about 18 days, and *tegitiplaga* 21 days. *T. popilliavora* attained the cocoon stage in 11 or 12 days in Chosen in early September but required 30 days or more in October and early November, whereas at Koiwai, in northern Japan, from 18 to 30 days were required during September, under temperature conditions approximating those of Chosen a month later.

TIME PASSED IN THE COCOON

So far as known, all Scoliidae in the temperate regions pass the winter within the cocoon, though this may be as a mature resting larva, a pupa, or a fully developed adult. *Scolia japonica* hibernates in the mature larval stage, while Campsomeris is largely in the pupal form, though there is some evidence to indicate that in certain southern localities a portion of the adult females of the latter carry through the winter. In the summer generations of the species having this habit, the period from the formation of the cocoon to the emergence of the adult comprises a minimum of three weeks.

Among the Tiphia having a single generation annually, approximately 10½ months of each year is passed within the cocoon. Of those species regarding which the winter stage is definitely known, *asericae*, *malayana*, and *vernalis* are found as adults, whereas *bicarinata*, *brevilineata*, *koreana*, *notopolita alleni*, *phyllophagae*, *popilliavora*, *tegitiplaga*, and *totopunctata* hibernate as mature larvae. Of the three first-named species some of the late-developing individuals may pass the winter in the advanced pupal stage. In general it may be said that the spring-emerging species pass the winter in the adult stage in the cocoon, and that the summer and fall species do so as mature larvae. The first group would comprise those species that might be expected to produce a second brood under somewhat more favorable temperature conditions.

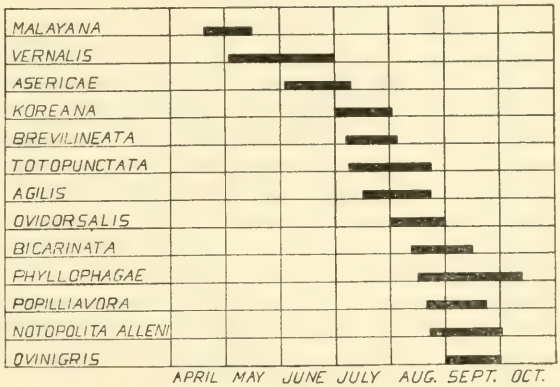

FIGURE 4.—Seasonal appearance of adults of Tiphia in Chosen

LENGTH OF ADULT LIFE

The larger Scoliidae, such as Scolia and Campsomeris, have a considerably longer period of adult life than does Tiphia, and this may extend over several months. Williams (*13*, *p. 59*) records a female of *Scolia manilae* Ashm. living nearly four months under insectary conditions, while the average of a series was 49 days.

Under normal field conditions the average length of life of Tiphia females is from 3 to 4 weeks, though this can be prolonged considerably under insectary conditions by withholding the opportunity for oviposition. Among the different species there is a considerable variation in the length of the period during which they may be found in the field. This shorter period on the part of some is not due to a shorter individual life, but rather to a greater uniformity in the time of emergence of some species than of others.

In Figure 4 there is shown, for comparative purposes, the period of adult occurrence of all the species of Tiphia studied at Suigen,

Chosen, the observations having all been made in the one general locality. Conditions being identical for all species, there is greater significance in the variations between them than would be the case were the data secured in widely separated sections with diverse factors influencing them.

FEEDING HABITS OF ADULTS

In all the species studied the general habit is for the females to feed for about three hours during the morning or at midday and then to spend the remainder of the day either resting in the soil or beneath vegetation on the surface, or in the search for host grubs for oviposition. The time of day at which they feed most extensively varies somewhat with the species. *T. popilliavora* in northern Japan was out in greatest numbers from 10 a. m. until 1 p. m., whereas *T. matura* A. and J. in India was to be found in numbers only from 8 to 11 a. m. The males generally appear slightly earlier in the morning than do the females and persist until about the middle of the afternoon. Some authors have noted a tendency on the part of the males of Scolia, Campsomeris, Dielis, and Elis to swarm at night, a habit not noticed with the Tiphia males.

The food materials required by the adult Scoliidae are derived from three general sources: (1) The exudations or secretions of aphids, scale insects, and various other Homoptera, these occurring particularly upon pine, oak, chestnut, etc.; (2) the blossoms of certain plants, especially of the Umbelliferae and Polygonaceae; and (3) nectar from various glands associated with foliage. The writers have observed Scolia and Campsomeris feeding only at blossoms, whereas Tiphia is represented as feeding at all these sources. Illingworth (*10*) records *Discolia soror* Smith as feeding very extensively upon the secretions of leaf hoppers on corn. In Table 1 are given the sources of food supply of the species dealt with, the Tiphia being listed in the order of their appearance during the season.

TABLE 1.—*Sources of food supply of the adults of the various species of Scoliidae listed as occurring in Japan and Chosen*

Species	Time of occurence	Honeydew from—	Blossoms	Nectar glands
Scolia japonica	May to September		Various	
Campsomeris annulata	All season		do	
Tiphia malayana	Late April to middle of May.	Aphids	Forsythia	
Tiphia vernalis	May to June	Aphids, bugs	do	
Tiphia tegitiplaga (I)	Late May to June	Aphids		
Tiphia biseculata (I)	June	do		
Tiphia asericae	do	Aphids, bugs		
Tiphia koreana	July to early August	do	Various	
Tiphia brevilineata	July to middle of August.	do		
Tiphia totopunctata	Early July to late August.	do		
Tiphia agilis	Middle of July to late August.	Aphids	Various	
Tiphia ovidorsalis	August	Aphids, bugs		
Tiphia bicarinata	August to middle of September.		Umbelliferae	
Tiphia phyllophagae	Middle of August to early October.		Seseli, Fagopyrum.	
Tiphia popilliavora	Middle of August to September.		Various	Polygonum
Tiphia notopolita alteni	Late August to September.		Seseli	
Tiphia biseculata (II)	do	Aphids	Fagopyrum	Sweetpotato
Tiphia tegitiplaga (II)	do			Do.
Tiphia ormyris	September		Umbelliferae	

Table 1 shows that the spring species of Tiphia confine their feeding almost exclusively to the liquid secretions of aphids and other bugs, with the exception of some *malayana* and *vernalis* feeding at Forsythia blossoms; that those appearing during midsummer feed either upon such secretions or at blossoms, though seldom both; and that the fall species are quite largely restricted to blossoms and nectar glands. The two species occurring at Miho, Japan, which have two generations a year, feed in the spring upon insect secretions and in the fall at the nectar glands of sweetpotato. The second generation of *biseculata*, however, has been noted to feed quite extensively upon aphid secretions upon pine.

The probable explanation of this seasonal change in feeding habit is that the insect secretions represent the favored food of the group, and that these aphids, scales, and bugs are particularly abundant during the early part of the season. They decrease in number by midsummer and are usually relatively scarce during the fall months. In this latter part of the season a much greater variety of flowering plants is available than during the spring.

The wasps are evidently attracted to their source of food by odor, and they usually feed in the general vicinity of the breeding grounds. A notable exception to this latter generalization is the case of *Tiphia matura* in India, which species was found to travel several miles, and to a considerably higher elevation, to the aphid-infested plants at which it fed, and then to return to the locality of origin for oviposition. In northern Japan *T. popilliavora* feeds at the blossoms and nectar glands of various plants, notably Polygonum, when growing on waste land situated at opposite sides of the breeding grounds. The females were always found in far greater numbers on the side of the field from which the wind was blowing.

In the utilization of Scoliidae in the natural control of Scarabaeidae the provision of an adequate supply of food plants, in the case of the blossom and nectar feeding species, would seem to be essential for attaining the desired results. The dispersion of the parasite can follow that of the host only so long as this condition is met, and large areas may be heavily infested with grubs and yet be practically immune from parasite attack, not because of any ineffectiveness of the parasites themselves but owing to the absence of their food supply. This condition seldom occurs in an area where there is any amount of waste land, as this connotes variety in vegetation, but is most likely to occur in relation to such Scarabaeidae as develop in cultivated soil and where a large area is under intensive cultivation for a single crop, which itself neither provides food for the adult Tiphia nor harbors insect species which do so.

Certain species of Tiphia have, in the adult stage, developed a slight tendency toward an entomophagous habit. This is shown in the case of *T. popilliavora*, the female of which, at the time of oviposition and immediately after the laying of the egg, often grasps a leg between her mandibles and bites upon it until a puncture is made or the leg entirely bitten off, after which she feeds upon the body fluids exuding from the wound. Field-collected grubs often show this type of injury, and the wound at times serves as a point of entrance for disease-producing organisms.

OVIPOSITION

It has not been possible to observe closely the sequence of events incident to oviposition by Scolia and Campsomeris, and these can only be surmised from the conditions observed when the cells containing ovipositing females are opened. In stinging, the parasite female faces in the same direction as the host grub, and dorsally of it, and the abdomen is then curved diagonally beneath the body so that the tip reaches the mid-ventral area of the thoracic segments. The stinging takes place near this point, and paralysis is effected through action upon one or more of the thoracic nerve ganglia. The sting is inserted several times and with considerable pressure. Illingworth (*10, p. 35*) states that *Campsomeris radula* Fab. attacks the grub by first seizing a mandible in her jaws and then inserting the sting, first in front of the anterior coxa and then in the throat.

Judging from the flaccid, extended condition of the grub body after oviposition by these parasites it would appear that a considerable kneading of the ventral surface must take place following stinging, though this has not been actually observed. Williams (*13, p. 56*), in describing the act of oviposition, does not mention this kneading in the case of *Scolia manilae*. With all species, the inert body of the host is left lying on its back.

PARALYSIS OF THE HOST

The influence of the sting of the various Scoliidae upon the host ranges from the complete and permanent paralysis effected by some of the larger genera to a very temporary immobility by Tiphia. All Scolia and Campsomeris known to the writers permanently paralyze the host grub, though this is not always complete, as in some instances a certain degree of disordered movement of the legs may be observed. In no case has complete or even partial recovery been noted. According to various authors the genera Elis and Dielis similarly paralyze the host grubs, as does also the South American genus Pterombus studied by Williams (*14, p. 149*).

The sting of Tiphia and the effect of the poison injected into the wound are much less severe than with the foregoing genera, resulting in a temporary and often incomplete paralysis lasting only 10 to 15 minutes in some species and extending to 30 minutes or slightly longer in others. While mobility is regained in a comparatively short time yet the full effects of the sting do not disappear for many hours, the more lasting effect being evident in a weakness in the abdominal region. No species of this genus is known to paralyze its prey permanently.

MANNER OF OVIPOSITION

In the case of both *Scolia japonica* and *Campsomeris annulata* the egg is placed upon the ventral surface of the body with its own ventral surface facing caudad, and with the posterior end lightly adhering to the derm of the host. From this position it would appear that during the actual deposition of the egg the body of the parasite female must lie parallel with that of the host, and facing caudad, rather than coiled transversely about it. This position dur-

ing the course of oviposition is not common to all members of these genera, for Illingworth (*10*, *Pl. 4*) shows the concave (ventral) surface of the egg of *C. radula* facing cephalad, and consequently the female parasite must face in the same direction as the host during the act of oviposition.

With respect to the genus Tiphia, the manner of oviposition of *T. popilliavora* has been described in some detail in a previous publication (*4*) and may be taken as representative of the group. By the use of a large gelatin capsule as a substitute for the soil cell of the grub the entire process of oviposition takes place very readily and can be closely observed under the binocular. The female approaches the grub from the rear, brings her head near to that of the host, and then lowers the abdomen diagonally behind and around the legs to effect stinging in the ventral mid-thoracic region. This stinging may be repeated many times, or until the grub becomes quiescent. Turning about, the female now devotes several minutes to a thorough kneading of the ventral surface of the abdomen with her mandibles. As a result, the body becomes flaccid and the abdomen relaxed and extended as compared with its normal turgid and curved condition. This accomplished, the parasite then grasps with her mandibles a fold of skin just above the lateral margin of the fifth or sixth abdominal segment, at the same time extending the body transversely across the dorsum of the host and bringing the abdomen across the ventral surface from the opposite side, thus forming almost a complete ring, the tip of the abdomen then being situated just beneath the head. The last abdominal segment of Tiphia bears at its extremity a roughened pygidium, and this is applied to the suture between the two segments and moved rapidly backwards and forwards for several minutes. The effect of this action is to broaden the groove for the reception of the egg and to wear away to a certain extent the integument of the body at this point, thus permitting its ready perforation by the young larva later. This extensive rasping of the integument is largely responsible for the rarity with which two or more eggs or larvae are found upon a single host grub. There is evidenced no disinclination whatever to oviposit upon a host already bearing an egg or young larva, but where these already occur they are, in most species, almost invariably broken or rubbed off before the succeeding egg is laid. This fresh egg is usually placed one segment in front of, or behind, the position of the earlier egg, rather than in the same suture. Grubs found in the field often bear a number of oviposition scars, though usually only the one egg, whereas in the laboratory instances have been observed of oviposition at least a dozen times upon the same grub, as evidenced by the two rows of oviposition scars in the intersegmental grooves between the second and successive segments to the eighth.

In several species this habit of rubbing off or destroying the eggs previously laid is not nearly so pronounced, and instances have been noted of grubs bearing as many as six fresh eggs upon the abdomen. This duplicate oviposition is particularly noticeable in the case of *T. bicarinata*.

The kneading of the body of the host is not habitual with all species of the genus: in fact, *popilliavora* seems to represent the extreme development of the habit. Those species that oviposit dor-

sally upon the thorax dispense with it entirely, and it is considerably reduced in extent in the case of such species as place their eggs ventrally on the anterior half of the body.

The normal habit of all Scoliidae is to locate the host grub in its cell in the soil, or in exceptional cases in plant tissue, sting it immediately, deposit the egg on the body, and then leave it in the same location in which it was first found. With some of the larger genera, however, the quiescent grub is buried deeply in the soil in a cell excavated by the female parasite, and the egg is then placed on it. This is particularly true of *Scolia*, and to a lesser extent of Campsomeris. During their feeding period the host grubs are quite near the soil surface, whereas those parasitized may be buried several feet deep, dependent on the physical condition of the soil. It is due to this habit of the females, of burying their prey, that cocoons of the above two genera are observed only in small numbers in the field, even though the number of adults present indicates their occurrence in abundance. No instance is known of Tiphia burying its host grub deeper than the normal feeding or resting cell, and the female always leaves the grub immediately after oviposition without any effort to modify the conditions under which it lies.

Although the habit of the family is to search out the host in its feeding cell or chamber, yet instances are known of various species, or, more exactly, individuals of various species, attacking their prey on the exposed surface of the ground and then burying it before oviposition, a manner identical with that of many of the other hunting wasps which store their cells with adult insects or larvae of various kinds. Gosse (*9*, *p. 120*) in Alabama, in 1859, recorded having seen a female *Scolia quadrimaculata* Fab. dragging a large lamellicorn grub along the surface of the ground to bury it. Ferton (*7*, *p. 409*) observed *Myzine andrei* Ferton in North Africa hunting a tenebrionid larva over the ground, and then stinging and burying it. In Illinois, Forbes (*8*, *p. 472*) noted Tiphia doing likewise with Phyllophaga grubs. In the present investigations this habit has been noted in the case of only a single species, *T. biseculata*, in Japan. In the particular locality in which this species occurs abundantly the soil is very sandy, and during heavy rains the Anomala grubs often come to the surface and wander about for a time. This is presumably due to the collapse of their soil cells. The females of *T. biseculata* become active very shortly after the rain ceases and may then be observed attacking the grubs which they find above ground.

POSITION OF THE EGG

The point of placement of the egg on the body of the host is quite constant among the individuals of any given species, but varies greatly between species and genera. In conjunction with this specificity in position another factor, the direction of the egg (that is, whether the anterior pole is directed towards the lateral margin or the median line of the body of the host) is of value. In Table 2 the direction and position of the eggs of the 17 treated species are given, the respective positions being also illustrated in Figure 5.

TABLE 2.—*Location and direction of the egg as placed by the various species of Japanese and Chosenese Scoliidae listed*

Species	Position of egg			Direction of egg
	Dorsal	Ventral	Lateral	
Scolia japonica		A4		V
Campsomeris annulata		A3		V
Tiphia tegitiplaga	T2-3			L
Tiphia koreana	T3			M
Tiphia ovidorsalis	T3			M
Tiphia totopunctata	T3			M
Tiphia biseculata		T3-A1		L
Tiphia phyllophagae		T3-A1		L
Tiphia vernalis		T3-A1		L
Tiphia agilis		A3-4		L
Tiphia bicarinata		A3-4		L
Tiphia brevilineata		A3-4		L
Tiphia malayana		A3-4		L
Tiphia ovinigris		A4-5		L
Tiphia popilliavora		A5-6, 6-7		M
Tiphia notopolita alleni		A7-8		L
Tiphia asericae			A7-8	M

Explanation of symbols:—T, on thorax; A, on abdomen; the numerals representing the respective segments of the body divisions. L, anterior pole of egg directed toward side of body; M, anterior pole directed toward the median line; V, vertical, with the posterior pole adhering to the host body.

In *Scolia japonica* and *Campsomeris annulata* the egg stands vertically upon its posterior end on the body of the host, and always on one of the middle abdominal segments. In respect to the former genus several writers have asserted that it is the anterior end that

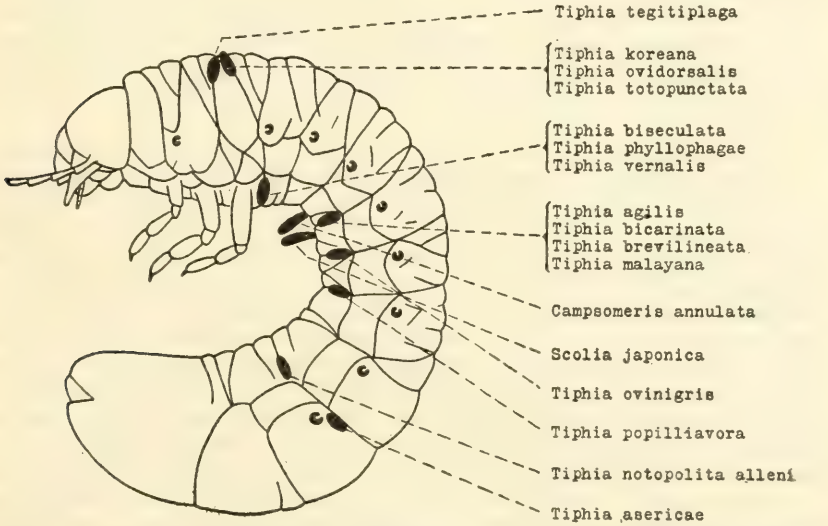

FIGURE 5.—Position of the egg upon the host grub of 17 species of Japanese and Chosenese Scoliidae

adheres to the host derm, but it is difficult to perceive how this reversal of position of the egg could be accomplished by the parasite.

The writers have not had the opportunity to observe the oviposition habits of Elis and Dielis. Box (*2*) has studied three species of the latter genus and found that the egg in each case was placed verti-

cally, while with *Elis xanthonotus* Roh. it was in a horizontal and transverse position. Davis (*5*) noted with *E. 5-cincta* Fab. that it was placed horizontally and diagonally across the body.

In Tiphia the egg always lies flat on the body, transversely in one of the segmental or intersegmental grooves. The greater number of species seem to fall into three general groups on the basis of egg placement, as follows:

(1) Egg placed dorsally in one of the grooves of the third thoracic segment and only slightly to one side of the median line. In this case the anterior pole of the egg is directed medially.

(2) Egg placed ventrally in the intersegmental groove between the third thoracic and the first abdominal segments, with the anterior pole directed laterad.

(3) Egg placed ventrally between the third and fourth abdominal segments, with the anterior pole directed laterad.

Of those depositing their eggs ventrally only a single species, *T. popilliavora*, has the anterior pole directed toward the median line, while *T. asericae*, which places its egg laterally just above the ninth spiracle, also has the pole directed medially.

This position of the anterior pole of the egg seems to be due to the length of the Tiphia female in relation to the circumference of the host body at the point at which the egg is laid. In those species in which the body of the parasite is of sufficient length to extend across the dorsum and then across the ventral surface as well, thus forming almost a complete ring, the anterior pole of the egg will be directed medially. If, however, it is too short for this and extends only to the side of the venter opposite the head of the female parasite the egg pole will consequently be directed laterad. With those species which oviposit dorsally on the thorax the body of the parasite extends first across the thorax of the host ventrally, rather than dorsally.

The egg position given for the various species is not absolutely constant, and many instances have been noted of eggs being placed one segment in front of, or behind, the normal position. It is not implied that the positions given in Table 2 are the only ones taken advantage of by the different species of Tiphia. Other species are known that oviposit upon the second thoracic segment dorsally, and between the second and third ventrally, the egg thus being found between the coxae of the last two pairs of legs; and it is probable that species will eventually be found which represent among them every intersegmental position between the first and the eighth abdominal segments. In *popilliavora* the normal egg position on the grubs of *Popillia japonica* in Japan, and in China on other Popillia, is between the fifth and sixth abdominal segments ventrally, whereas in Chosen, on *P. atrocoerulea* and *P. castanoptera*, it is largely between the sixth and seventh, only about one-third being between the fifth and sixth.

NUMBER OF EGGS

No complete oviposition records were secured for *Scolia japonica* or *Campsomeris annulata*, but general observations indicate that their reproductive potential somewhat exceeds that of the various species of Tiphia in the same region.

Williams (*13, p. 58*) records *Scolia manilae* as depositing a maximum of 52 eggs during a period of 79 days, and Illingworth (*10, p. 33*) in Australia secured 84 and 95, respectively, from two females of *Campsomeris tasmaniensis* Sauss., with the general average for the series under observation slightly more than one egg per day. The rate of oviposition of these genera is about the same as that in Tiphia but extends over a considerably longer period of time.

Among the Tiphia which have been tested sufficiently to give an idea of their normal capacity for oviposition it has been found that 40 eggs represent approximately the general maximum. Of the three species that have been reared very extensively in the insectary, *popilliavora* in Japan deposited an average of nearly 2 eggs per day during the oviposition period, whereas *vernalis* in Chosen and *matura* in India averaged only 1 in two days, these representing the extremes of the genus in this respect. Under field conditions it is probable that this difference in rate is not so great, that mentioned being possibly due more to a difference in adaptability of the various species to the insectary conditions provided. In the breeding cages the greatest number of eggs secured from a single female in one day was 6, this being from *T. bicarinata*. Under forcing conditions in gelatin capsules a female of *popilliavora* was induced to deposit 8 eggs during a period of six hours.

A notable exception to the above-mentioned average capacity for oviposition is that of the Chinese race of *popilliavora* studied by H. A. Jaynes at Penniu. In the investigations of 1925 a series of 46 females yielded an average of 54.9 eggs each, while one of them produced the very exceptional total of 115. This is in marked contrast to the results secured with the Japanese and Chosenese races, the general average of these being approximately doubled. These observations, in conjunction with various published reports by other authors, indicate that the reproductive potential of the tropical and subtropical forms is considerably greater than that of those species occurring in the more temperate regions.

D'Emmerez (*6*) presents figures for Elis and Tiphia in Mauritius which differ markedly from those above mentioned. In the case of *Elis rufa* Lep. he states that, in captivity, host larvae are normally parasitized by twos, at intervals of from six to eight days, and this conclusion was corroborated by field observations. His examination of the reproductive systems of the females showed one mature egg in each oviduct, while those still in the ovaries were of markedly smaller size. With *Tiphia parallela* Smith the normal egg capacity is said to be approximately 70, with the same rate and intervals between depositions as given for *E. rufa*. Such periodicity in oviposition has not been noted in any of the 35 or more scoliid species studied in the course of the writers' investigations.

HOST MORTALITY THROUGH MECHANICAL INJURY

In the larger Scoliidae particularly the reproductive potential of the species does not necessarily indicate the maximum host mortality that may be attained. The permanent paralysis and consequent death of the grub are brought about in a variable proportion of cases by Scolia, Campsomeris, and others, without oviposition, and from the point of view of natural control this factor represents

an added value. With some known parasitic Hymenoptera the number of hosts thus destroyed is far greater than that caused by the feeding of the progeny. In the laboratory the proportion destroyed in this way by Scolia and Campsomeris is large, but this is difficult of determination in the field. That it does occur under normal conditions is unquestionable, as grubs very evidently paralyzed by species of one of these genera have been found in the field. In his report on the parasites of scarabaeid grubs in Queensland Illingworth, who worked with the larger species (*10, p. 25*), states that the females of Scoliidae often paralyze a much greater number of grubs than actually receive eggs.

This factor is of much less importance in Tiphia, where recovery from the effects of the sting is complete, and the mortality effected, aside from that due to normal larval development, is very limited. Such of these as may die without being successfully parasitized do so as a result of the entrance of disease organisms at feeding punctures rather than of direct mechanical injury. This point has been discussed under the feeding habits of the adults.

THE IMMATURE STAGES

THE EGG

The eggs of Scolia and Campsomeris are quite similar in size and form. Those of average-sized species measure 2 to 4 mm. in length, with the maximum width, near the anterior end, approximately one-fourth to one-third of the length, and with both poles smoothly rounded. The ventral side is straight or very slightly concave, with the dorsum somewhat arched. The eggs at first are a translucent white but become somewhat yellowish or cream-colored towards the end of the incubation period.

In Tiphia there is likewise very little diversification either in size or form, the eggs of the largest species being about 2 mm. in length and 0.7 mm. in width, with the dorsum slightly convex and the ventral line nearly straight. In the smallest species studied the egg is approximately half the above length. The chorion is, in general, considerably heavier than in Scolia or Campsomeris. The one distinguishing character among the eggs of this genus is the color, and this is of very limited application. In the great majority of species the egg is white when laid but quickly assumes an amber tint of varying depth, owing largely to the drying out and oxidation of the mucilaginous material which envelops it and by means of which it adheres to the integument of the host. A further slight darkening in color occurs as incubation proceeds. The extreme in egg color is represented by *ovinigris* and *phyllophagae*, the only two species in the series parasitic upon Phyllophaga, in which it is nearly black. Intermediate in the color range are the eggs of *agilis*, *notopolita*, *alleni*, and *totopunctata*, which are brownish black, and of *asericae*, which are a dark gray towards the end of the incubation period.

Among the different species of Tiphia there is a considerable variation in the firmness with which the eggs are fastened to the host body, and in some species apparently the amount or degree of adhesiveness of the material used is much greater than in others. In the case of *bisseulata* and *asericae* a great deal of difficulty was experi-

enced in the breeding work owing to the high percentage of eggs which were rubbed off. A similar condition was noted in several other species, and this was in marked contrast to the relatively high percentage of development secured with *phyllophagae*, *popilliavora*, and *vernalis*. The position of the egg on the body of the host offers no indication of the probable loss from this cause, as that of *bisecula* is placed between the last thoracic and the first abdominal segments, a relatively protected position, whereas those placed dorsally on the thorax would seem to be most exposed to injury and loss, yet this was not reflected in the breeding results or indicated by field observations. The latter revealed, through the presence of oviposition "scars" (the dried, amber-colored adhesive material which remains on the host integument when the egg is removed), that much the greater loss usually occurs among those species which place the egg in the mid-ventral region.

HATCHING

In *Scolia japonica* and *Campsomeris annulata* hatching is accomplished by a median and irregularly longitudinal splitting of the chorion over the head and the thoracic segments. The fore part of the body of the young larva then emerges from the opening and is bent ventrally until the head comes in contact with the host body, at which point the feeding puncture is made. This mode of emergence from the egg gives a constant position for the feeding puncture with respect to the parasite egg, it being always on the median ventral line of the host body one segment caudad of that on which the egg is situated. In such other species and genera as place the egg with its ventral surface facing cephalad, this feeding position would be on the segment in front of, rather than behind, the egg.

In the hatching of the egg of Tiphia the median split of the chorion also occurs over the head and thoracic segments, and this portion of the larval body is then extruded slightly forward and the feeding puncture immediately made. As feeding progresses and the body enlarges, the split extends dorsally nearly to the posterior end, the caudal segments being entirely freed before the end of the primary stage. The cast shell then remains as a pad beneath the body of the larva, adhering both to it and to the integument of the host.

THE LARVA

FEEDING HABITS

The feeding habits of Scolia and Campsomeris larvae differ markedly from those of Tiphia in several respects. In the former two genera a very noticeable feeding puncture is made, and the head of the first-stage larva becomes imbedded in the body of the host. As development progresses not only the head but the thoracic segments as well are within the body. To permit of this, or as a result of it, the thoracic segments are considerably elongated and much narrower than the abdomen. By the time the larva attains the last instar the aperture in the host derm is slightly less than 2 mm. in diameter, and an appreciable quantity of body fluids exudes from the

wound and appears as a ring about the "neck" of the parasite larva. In the early larval stages feeding is in the anterior portions of the host body, and the exposed abdomen of the parasite consequently lies diagonally on that of the host and is directed somewhat caudad. In the final larval stage feeding is completed in the posterior portions of the host body, and the entire contents are consumed, though none of the integument is eaten.

In view of the grossness of the feeding habits of these two genera, resulting in a very large wound and in the constant exudation of body fluids at this point, it is surprising that putrefaction does not set in before the completion of feeding. With a mechanical injury producing such a wound, decay would be evidenced very quickly, but there is no trace of it in the parasitized grubs. The very short feeding period guards against this contingency to a certain extent. It has not been possible to distinguish the point at which complete paralysis ceases and death takes place, but this is believed to be about the middle of the feeding period of the parasite.

Illingworth (*10, p. 35*) states that the larva of *Campsomeris radula*, when disturbed just prior to pupation, ejects water from the tip of the abdomen to a distance of 6 inches or more. Box (*2, p. 317*) states that those of the larger Scoliidae in general have this habit. In the writers' investigations, however, this has not been noted to occur in *S. japoncia* or *C. annulata*.

In Tiphia the manner of feeding corresponds more nearly to a true parasitic habit than does the qualified predatory habit of Scolia and Campsomeris. In the first four larval stages feeding is entirely suctorial, and the puncture is consequently of such minute size that when the larva is removed from the host body there is no exudation of fluids from the wound. The body of the larva in all stages is of normal form, widest in the mid-abdominal region, and with no appreciable narrowing or elongation of the thoracic segments.

In the last larval stage feeding by suctorial action gives way to the direct use of the mandibles, and the normal habit of all species is to consume not only the entire body contents but also the integument, with the exception of the head, legs, and at times a portion of the thorax.

During the early stages the body of the Tiphia larva lies transversely on that of the host. In those species in which the egg is placed ventrally near the lateral margin, and with the anterior pole directed toward the margin of the host body, the body of the parasite larva extends across the venter, whereas in the case of those which place the egg with the pole directed toward the median line the posterior portion of the parasite body curves over the lateral margin and extends dorsally.

NUMBER OF LARVAL INSTARS

In Scolia and Campsomeris there are four larval instars, and the three cast skins do not remain attached in a fixed position to the bodies of the succeeding instars or to that of the host. In contrast to this there are five stages in Tiphia, and the eggshell and the four cast skins remain in leaflike form adhering to the ventral side of the following stages. The eggshell, which forms a part of the ventral

pad, still adheres to the integument of the host, and the mandibles of each of the exuvia remain imbedded in their respective feeding punctures. Molting is effected by a longitudinal dorsal split over the thorax and abdomen, and the head, upon being extruded from the old skin, is extended slightly forward of the previous position, and a new feeding puncture is made. In figure 6 is shown diagrammatically a fifth-instar Tiphia larva with the four cast skins and the eggshell outlined beneath, and also a separate feeding puncture for each stage, as represented by the regularly spaced heads of the exuvia.

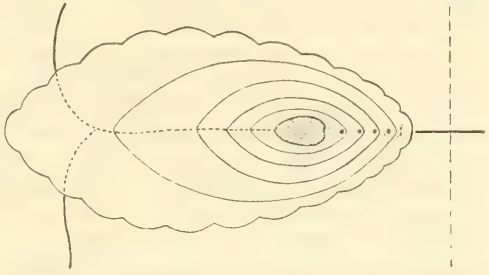

FIGURE 6.—Diagrammatic representation of the position of the successive larval stages of Tiphia in situ upon the host, showing the mouth parts remaining in the old feeding punctures. Largest outline represents the fifth and last larval stage

The mandibles of *Scolia japonica*, *Campsomeris annulata*, and *Tiphia koreana* are illustrated in Figure 7, and the differences shown serve as a ready means of distinguishing between larvae of these three genera. Those of Scolia and Campsomeris have three large teeth and are quite similar in general form, except that in Scolia the front tooth is proportionately somewhat larger and the grooves between the teeth are V-shaped, whereas in Campsomeris these grooves are narrower and the sides very nearly parallel. In Tiphia the three large teeth are also present, the first broader and larger than the remaining two, which are subequal with the grooves broadly V-shaped. The one ready character which distinguishes the mandibles of this genus from those of Scolia and Campsomeris is the possession of an additional small tooth at the

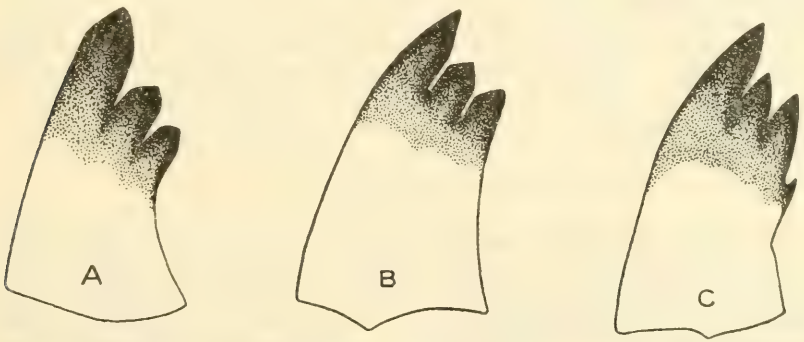

FIGURE 7.—Mandibles of mature scoliid larvae: A, *Scolia japonica;* B, *Campsomeris annulata;* C, *Tiphia koreana*

basal margin of the third of the main teeth. This varies somewhat in size according to the species but has been noted in all the species studied.

THE COCOON

In *Scolia japonica* the cocoon is broadly oval in form, the posterior end only slightly narrower than the anterior, and both evenly

rounded. It is dark brown with a somewhat glazed surface and lacks any loose covering of silk on the outside. That of *Campsomeris annulata* is of the same general form, reddish brown, and enveloped in a fairly heavy mass of silken strands, giving it a pronounced woolly appearance. The cocoon wall is comparatively delicate.

The Tiphia cocoon is quite distinct from those of the other genera in that, whereas the anterior end is broad and smoothly rounded, the posterior end is much narrowed and drawn out to a distinct point. The cocoon wall is very dense and compact, with a highly glazed surface inside, and surrounding it is a mass of silken strands of varying extent, forming either a loosely woven fluffy covering or separated into one or more thin and distinct envelopes. In *agilis*, *biseculata*, *notopolita alleni*, *ovidorsalis*, *phyllophagae*, *popilliavora*, *tegitiplaga*, and *vernalis* this covering is loose and fluffy, and not separable into distinct layers. This is true also of *asericae* and *malayana*, but there is much less of the covering. In *brevilineata*, *koreana*, and *totopunctata* the envelopes are quite distinct. *Tiphia brevilineata* has a cocoon quite different from that of the other species in that it is heavy and parchmentlike, with the surface appearing uneven but somewhat glazed and lacking almost entirely the loose outer strands of silk. Except in form it is thus more nearly comparable to the cocoon of Scolia than to the typical Tiphia cocoon.

The color of the cocoons in the genus Tiphia ranges from tan to a deep brown, those of the smaller species being in general the lighter colored. The color has been found to be due, in part at least, to the composition of the soil in which it is spun, as in a number of instances noted larvae that have been forced to form the cocoon in glass containers or paper cones free from soil produce nearly white cocoons.

In Scolia and Campsomeris the meconium is discharged in liquid form and is absorbed by the cocoon, considerably discoloring it in irregular patches. There is no trace of a solid meconial pad at the base of the cocoon, and only the cast skins of the larva and pupa may be found in the cocoon upon examination after the emergence of the adult. Tiphia forms a very compact meconial pad pressed down into the narrow tip of the cocoon with the upper surface, if somewhat concave, fitting rather closely about the tip of the abdomen of the pupa.

MANNER OF EMERGENCE FROM THE COCOON

The adults of *Scolia japonica* and *Campsomeris annulata* effect emergence from the cocoon by cutting a relatively large circular cap from the anterior end, the plane of the opening being at right angles to the longitudinal axis of the cocoon. All Tiphia adults emerge through a hole of irregular outline eaten out at one side of the cocoon near the anterior end, this being barely large enough to permit of the passage of the body.

According to Box (*2*, *p. 318*) all Dielis emerge by cutting a neat lid from the anterior end, whereas Elis, according to Davis (*5*) and Box, has the same manner of emergence as Tiphia.

The emergence holes of secondary parasites may at times be mistaken for those of the scoliid itself. The Bombyliidae remove a circular cap from the anterior end of the cocoon, but this can be recog-

nized by the fact that the edges are always quite ragged, on account of the cuts being made by the rasping of the head crown of the pupa, rather than a smooth cut with the mandibles as in Scolia and Campsomeris. The Rhipiphoridae cut away a similar cap, and cocoons from which these have emerged can be distinguished only by an examination of the larval remains contained in them. With Perilampus the hole is in the same position as that of Tiphia, but usually larger and more irregular in outline. Cocoons of Tiphia from which Mutillidae have emerged require an examination of the contents for verification, the holes being of similar form, size, and position.

PARTHENOGENESIS

No extended experiments have been made with the Japanese and Chosenese Scoliidae with respect to parthenogenesis, as the entire stock of reared cocoons of the principal species studied was forwarded to the United States for colonization purposes. The existence of this mode of reproduction has been demonstrated in some species of the family and its occurrence denied in others. Davis (*5*) states that it does not occur in *Elis 5-cincta* Fab., though unmated females will sting grubs. According to Illingworth (*10*) *Campsomeris radula* produces largely males when unmated, though also a few females, and he states that in general a smaller number of eggs is laid by such females. The production of both sexes of progeny by unmated females, even in the disproportionate numbers given, is a very unusual occurrence in the parasitic Hymenoptera. The customary result is the production of males only, or, in a relatively few instances, of females only.

NATURAL ENEMIES

In the course of the investigations on the Scoliidae in Japan and Chosen, it was not possible to make extended field collections of cocoons for the rearing of such parasites as might be contained in them. This difficulty was due to the intensive cultivation practiced in these countries, as a result of which very little waste land was available in which diggings could be made. Ten natural enemies, as shown in Table 3, have been noted, of which *Palarus saishiuensis* Okamoto was found in Chosen and the remaining species in Assam, India.

This wasp, *P. saishiuensis*, is one of the hunting wasps which stores its nest largely with adult Apidae, Sphecidae, and Scoliidae. The species is known to be well distributed in Chosen and in the island of Saishiu (Quelpart), but has not been recorded from Japan. A general account of the habits of this insect has been published by one of the writers (*12*).

The female wasps are found most commonly during August and September. Their burrows are invariably situated in rather heavy clay soil, the surface somewhat sloping, and with little or no vegetation upon it. In Figure 8 is shown a section of a typical burrow with the enlarged cell at the bottom, in which the victims are placed and the egg deposited among them. The burrow extends for a distance of from 8 to 12 inches into the soil and at an angle of about 40° from the horizontal. The slope of the burrow is not continuous

but is broken from two to four times by a short diversion after each of which the general trend is resumed. When the excavation of the nest is complete, the mouth of the burrow is filled and covered with sand and dust.

TABLE 3.—*Insect enemies of the scoliid parasites found in Chosen and in India*

Parasite	Family	Scoliid host
Hymenoptera:		
Palarus saishiuensis Okam.	Sphecidae	*Tiphia* spp.
Mutilla stephani Magr.	Mutillidae	*Tiphia matura* A. and J.
Mutilla sp., near *antennata* Sm.	do	*Tiphia* sp.
Perilampus sp.	Perilampidae	*Tiphia pullivora* A. and J.
Coleoptera:		
Macrosaigon pusillum Gerst.	Rhipiphoridae	*Tiphia matura* A. and J.; *Tiphia pullivora* A. and J.
Diptera:		
Hyperalonia oenomaus Rond.	Bombyliidae	*Scolia* sp.; *Campsomeris* sp.; *Tiphia* sp.
Exoprosopa sipho Ald.	do	*Tiphia pullivora* A. and J.
Aphoebantus clauseni Ald.	do	Do.
Aphoebantus seriatus Ald.	do	Do.
Nematode:		
Eomermis tenuissima Cobb.		*Tiphia matura* A. and J.; *Tiphia pullivora* A. and J.

The search for wasps with which to stock the nest takes place largely during the middle of the day. The actual capture and stinging has not been observed, but numerous females were noted bringing the paralyzed prey to the burrow. It is deposited near the entrance of the burrow, and the female then leaves it and scrapes away the sand and dust from the entrance with her forelegs. She descends into the burrow, then turns about and comes to the surface, after which she seizes the prey by the thorax and drags it into the burrow. (Fig. 8, inset.) It appears probable that each burrow is completed and stocked the same day it is started, and successive returns of the female with freshly captured prey were seen to occur at intervals of 5 to 10 minutes.

In nine completed nests, which were excavated and the contents recorded, 73 paralyzed wasps were found, with 14 as the maximum in one cell. By families the numbers of individuals were as follows:

Scoliidae	48 (Tiphia only).
Apidae	21 (5 or more species).
Sphecidae	2 (Oxybelus, Cerceris).
Mirmosidae	1 (Mirmosa).
Ichneumonidae	1.

From the foregoing list it will be seen that the greater proportion of the victims of this wasp are Tiphia, the remainder being largely various Apidae approximating Tiphia in size. It is evident that the numerical abundance of a hunting wasp such as this could affect decidedly the efficiency of such of these scarabaeid parasites as are of suitable size and occur during the latter part of the summer. The injurious effect is accentuated by the fact that by far the greater proportion of the wasps killed are females.

Only an occasional specimen of Mutilla was secured from the cocoons of *Tiphia matura* collected in India. An examination of the contents of these parasitized cocoons showed that development

of the parasite had been completed upon the mature Tiphia larvae. The mandibles of the last-stage mutillid larva are larger and differ markedly in form from those of any of the Scoliidae. Emergence from the cocoon is effected through a rather irregular hole near the anterior end, very similar to that of the host though possibly somewhat smaller.

Among the thousands of cocoons of *Tiphia pullivora* and others collected in India and shipped to the United States during the period from 1925 to 1927, inclusive, several each year yielded adults of *Perilampus* sp. A number of those retained in India were isolated prior to emergence and the contents later examined. The form of the mandibles of the larva showed the cocoons to be unquestionably those of Tiphia. The cast skins of the Perilampus

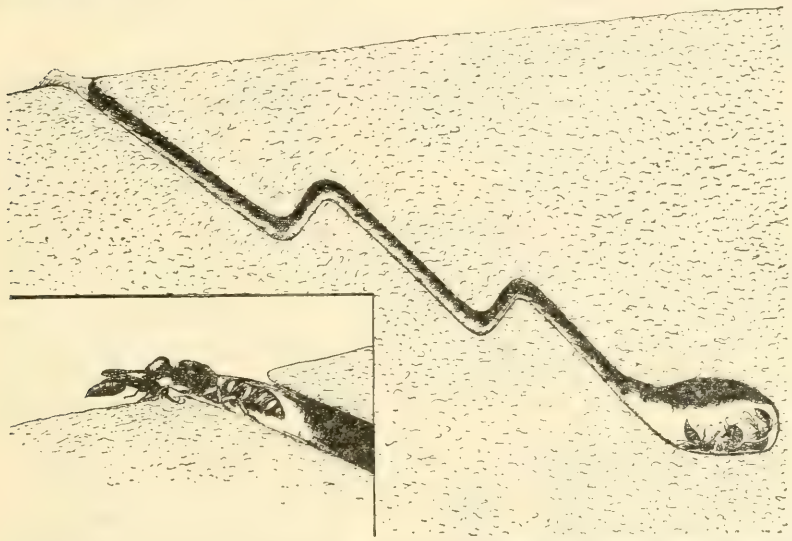

FIGURE 8.—The burrow of *Palarus saishiucnsis*, showing the rearing chamber at the bottom, × ½; and (inset) a female dragging her prey into the mouth of the burrow, natural size

planidia were found still attached to the cast larval skin of the host, though development had been completed upon the pupae.

It is not considered that Perilampus is a normal parasite of Tiphia but rather that these few instances represent stray planidia which in some manner had gained access to the host larvae, either in the feeding stage or after the formation of the cocoons and once there were able to develop to maturity upon them. The diversity in the previously known hosts of Perilampus is so great that development upon Tiphia is not at all surprising, but the manner of reaching these larvae in the soil is difficult to explain.

The smaller Tiphia species in India are quite generally, and often fairly heavily, attacked by rhipiphorid parasites. One lot of 250 cocoons of *Tiphia pullivora* collected during July at Shillong was found upon examination to contain 1 mature larva, 6 pupae, and 64 adults of *Macrosaigon pusillum* Gerst.[3], this representing a para-

[3] Determined by E. A. Chapin.

sitization of 28.4 per cent. In the case of this parasite the Tiphia hosts are killed in the mature larval stage, and the adults of the parasite emerge slightly earlier than would those of the host. Emergence is effected by cutting away a neat cap from the anterior end of the cocoon.

The life history of this group of beetles in the rôle of parasites in scoliid cocoons has not been studied, and there is considerable doubt as to the exact manner in which the primary larvae gain access to the host. Neither is it known whether it is the immature larval form upon the scarabaeid grub which is first attacked or the mature form within the cocoon. General observations indicate a mode of development somewhat similar to that of Hyperalonia and some other Bombyliidae.

Among the females of *M. pusillum* there is an unusual range of color forms, some being entirely black, others with red thorax, and finally some with both the thorax and abdomen red.

All four species of Bombyliidae listed in Table 3 were reared from isolated cocoons. The species present in the field in greatest numbers was *Hyperalonia oenomaus*, which effected each year a parasitization of 50 to 60 per cent of the cocoons of a large red-legged Tiphia which itself attacks *Anomala diomphalia*. An account of the life history of this parasite has been published by the senior writer in an earlier paper (*3*). In brief it may be stated that the adult flies appear in the field immediately after the period covered by the host adults, the eggs are presumably deposited upon the surface of the ground, and the young larvae find their way into the cocoons and develop as external parasites of the resting larvae. The active feeding period covers 10 to 15 days. There is a single generation each year, and the winter is passed in the mature larval stage within the host cocoon.

A small proportion of the cocoons of *Tiphia pullivora* and *T. matura* which had been collected for rearing purposes were found to yield instead a species of nematode, which has been described by N. A. Cobb as *Eomermis tenuissima*. These emerged from the cocoons early in July, this being only shortly after the formation of the cocoon of *T. matura* and immediately preceding the normal time of emergence of *T. pullivora*.

SUMMARY

All the scoliid species studied have been found to be parasitic on scarabaeid grubs of the subfamilies Melolonthinae and Rutelinae.

The food substances required by the adults come from three general sources—(1) the secretions of aphids, scales, and various other Homoptera, (2) certain plant blossoms, and (3) nectar from various glands associated with foliage. The dispersion of the parasite can therefore follow that of the host only so far as the range of its particular food supply extends.

On the basis of the writers' investigations upon the Scoliidae parasitic upon scarabaeid grubs, and supported by published data of other writers, the following general habits may be given for the different genera under discussion:

(1) In Scolia, Campsomeris, Dielis, and Elis there is a marked tendency toward swarming of the males at night. This habit has not been noted in Tiphia.

(2) Paralysis of the host is permanent in the case of Scolia, Campsomeris, Dielis, and Elis, and only temporary in Tiphia. In the first four genera the host grub is usually buried more deeply in the soil than its normal feeding level.

(3) In Scolia, Campsomeris, and Dielis, the egg is placed perpendicularly upon the ventral surface of the abdomen of the host, whereas in Elis it lies horizontally and diagonally in the same general region. In Tiphia it is placed transversely in a segmental or intersegmental groove, and either dorsally on the thorax or ventrally between any two body segments. The egg position varies with the species but is constant for each.

(4) In Scolia and Campsomeris and, to a modified extent, in Dielis and Elis the anterior portions of the body of the larva are thrust into the feeding puncture, whereas in Tiphia feeding is suctorial. In Scolia and Campsomeris no portion of the integument is eaten, whereas the Tiphia larva consumes all but the head and the more heavily chitinized portions of the thorax following the completion of feeding upon the body fluids.

(5) The cocoons of Scolia, Campsomeris, Dielis, and Elis are smoothly rounded at both ends, as contrasted with the very pointed posterior end of that of Tiphia.

(6) The solid meconial pad is absent in the cocoons of Scolia and Campsomeris, but present in that of Tiphia.

(7) In Scolia, Campsomeris, and Dielis emergence from the cocoon is effected by cutting away a circular cap at the anterior end, whereas in Elis and Tiphia an irregular hole of much smaller size is eaten out at one side near the anterior end.

An account is given of the natural enemies of the Scoliidae encountered during the course of the investigations in the various countries.

Of the Hymenoptera, *Palarus saishiuensis*, a sphecid wasp studied in Chosen, stores its nests with adult Tiphia and certain other wasps of similar size. Two species of Mutilla and one of Perilampus were reared from the cocoons of Tiphia in India, though in very small numbers.

The rhipiphorid beetle *Macrosaigon pusillum* was found quite frequently in the cocoons of *T. pullivora* in India.

Four species of bombyliid flies are listed as having been reared from the cocoons of either Scolia, Campsomeris, or Tiphia in India. *Hyperalonia oenomaus* is the only one of these occurring in large numbers, and each year it parasitized from 50 to 65 per cent of the overwintering cocoons of an undetermined species of Tiphia.

The nematode *Eomermis tenuissima* was reared occasionally during the summer from cocoons of *Tiphia pullivora* and *T. matura*.

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CRESTED WHEATGRASS AS COMPARED WITH BROMEGRASS, SLENDER WHEATGRASS, AND OTHER HAY AND PASTURE CROPS FOR THE NORTHERN GREAT PLAINS

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In Cooperation with the Agricultural Experiment Stations of Montana, North Dakota, and Wyoming

CONTENTS

	Page
Introduction	1
History	2
Description	3
Characteristics	3
Adaptation	5
Culture	7
Seed bed	7
Time of seeding	7
Method of seeding	8
Rate of seeding	12
Cultivation	12
Composition	13
Experiments at Dickinson, N. Dak.	13
Experiments at Mandan, N. Dak.	15
Utilization	16
As a hay crop	16
Relation of age of stand to productivity	26
For pasture	27
For improvement of range and reseeding abandoned plowed areas	29
For lawns	29
Seed production	30
Viability of seed	32
Diseases	32
Weed control	33
Summary	33
Literature cited	34

INTRODUCTION

The need has long been recognized for a perennial grass that will produce greater yields of hay and more abundant pasturage under conditions of limited water supply than can be obtained from native grasses in the United States. In an effort to obtain such a grass, seed has been procured from many foreign sources and tested at several points in the Great Plains. Bromegrass (*Bromus inermis* Leyss.) introduced into the United States in 1884, has been for years the outstanding cultivated grass in the northern Great Plains, and although it has played an important part in the agriculture of that region, there still remains a need for a more productive drought-resistant grass, and efforts are continually being directed toward that objective. As a

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[2] The authors acknowledge data furnished and cooperation given at various times by John M. Stephens, P. V. Cardon, Albert Osenbrug, I. J. Jensen, N. F. Woodward, and Harold E. Tower at Moccasin, Mont.; B. Dundas, Dickinson, N. Dak.; August L. Nelson, Archer, Wyo.; Ray S. Towle, Sheridan, Wyo.; Samuel Garver, Redfield, S. Dak.; Oscar R. Mathews, Ardmore, S. Dak.; and C. E. Hill, Waterville, Wash.

result of these efforts, crested wheatgrass (*Agropyron cristatum* Gaertn.) was introduced several years ago, and after thorough testing it has been found to possess considerable promise for the cold, dry regions of the United States. While it succeeds better under certain conditions than bromegrass, it is not to be assumed that bromegrass will be replaced by crested wheatgrass, as there are locations where the bromegrass gives more satisfactory results. Slender wheatgrass (*A. tenerum* Vasey) is grown to some extent, and although it usually produces well for two or three years it is much shorter lived than crested wheatgrass or bromegrass.

Crested-wheatgrass hay is more palatable to livestock than bromegrass hay and over a period of years has given somewhat greater yields, owing to the fact that bromegrass tends to become sod bound after two or three years. For preventing washing and to stop washing where it has already started, bromegrass is more effective than crested wheatgrass.

HISTORY

Crested wheatgrass is a native of the cold, dry plains of Russia and Siberia. While an occasional specimen had been reported in the United States at an earlier date, it was first introduced through the efforts of the United States Department of Agriculture in 1898, the seed having been sent in by N. E. Hansen, of the South Dakota Agricultural College, while engaged in plant-exploration work for the department in Russia and Siberia. Five lots of seed received at that time were assigned S. P. I. Nos.[3] 835, 837, 838, 1010, and 1012, but there are no available records of tests with any of these lots of seed. Small samples of seed received from Sweden in 1905 and from the Royal Botanical Gardens, Dublin, Ireland, were sown at the Arlington Experiment Farm, Rosslyn, Va., in 1906, but failed to germinate. That year seed of crested wheatgrass was received through the Moscow Botanical Gardens, Moscow, Russia, under S. P. I. No. 19536, together with seed of S. P. I. Nos. 19537 to 19541, inclusive, under the name *Agropyron desertorum*,[4] which resembled *A. cristatum* very closely in growth characteristics and adaptation. Other lots of seed were received in 1907 through Frank N. Meyer and N. E. Hansen, both of whom were on plant-exploration expeditions for the United States Department of Agriculture. As far as is known, all of the crested wheatgrass being grown in the United States at the present time traces back to importations made in 1906 under S. P. I. Nos. 19536 to 19541, inclusive, or to later importations.

The grass is known to have been grown at the South Dakota Agricultural Experiment Station at Brookings shortly after 1900, and at Highmore, S. Dak., as early as 1906. From information available it appears that crested wheatgrass was first sown at the Arlington Experiment Farm in 1906. Other lots of seed were sown at Arlington farm and at Pullman, Wash., and Chico, Calif., in 1907. The first seeding at the Belle Fourche Field Station, Newell, S. Dak., was made in 1908 and consisted of S. P. I. Nos. 19536 to 19541, inclusive (24).[5] No. 19536 proved to be fairly uniform, having broad

[3] A series of numbers of the Division of Foreign Plant Introduction, formerly Office of Foreign Seed and Plant Introduction.

[4] *Agropyron cristatum* and *A. desertorum* are so similar that both are included under the name crested wheatgrass in this bulletin.

[5] Italic numbers in parenthesis refer to Literature Cited, p. 34.

spikes and awned seed. Nos. 19537 to 19541 were nearly identical, being taller and more productive than No. 19536. Seed of these numbers produced at Newell was sent to Akron, Colo., Ardmore, S. Dak., and to several other stations in the northern Great Plains. The first seeding in North Dakota seems to have been made at the Dickinson substation of the State agricultural experiment station in 1909. The possibilities of the grass did not attract much attention, however, until 1915, the year it was sown at the United States Northern Great Plains Field Station at Mandan, N. Dak., and at the Judith Basin Branch Station of the Montana Agricultural Experiment Station, Moccasin, Mont.

At present crested wheatgrass is being tested at most of the experiment stations in the northern Great Plains and in the prairie Provinces of Canada. Seed was first produced on a commercial scale by a farmer in Montana shortly after 1920, and, although the value of the grass had been demonstrated as a result of more than 20 years' experience in growing it, seed was first listed by seedsmen in 1929, when it was offered for sale by a dealer in North Dakota. During the last 10 years, however, considerable seed has been distributed by several State experiment stations and by the United States Department of Agriculture.

DESCRIPTION

Crested wheatgrass (*Agropyron cristatum*) is a long-lived perennial bunch grass. (Fig. 1.) It is closely related botanically to slender wheatgrass (*A. tenerum*) and western wheatgrass (*A. smithii* Rydb.), both native to the northern Great Plains. The head or spike of crested wheatgrass is 2 to 4 inches long, being shorter but much broader than that of slender wheatgrass. In general appearance it is flat and oftentimes more or less fan shaped. (Fig. 2.) The crowded spikelets tend to stand out from the axis of the spike, which therefore appears rather broad. In contrast, the spikelets of slender wheatgrass are more widely spaced and lie closer to the axis, forming a comparatively slender spike. The seed is about the same shape as that of slender wheatgrass but only about one-half as large. (Fig. 3.) In some types the seeds have decided awns, while others are practically awnless. The stems of crested wheatgrass are generally fine, and the leaves are medium abundant and somewhat darker colored than slender wheatgrass. Both stems and leaves retain their color remarkably well.

CHARACTERISTICS

Crested wheatgrass has a longer productive period than slender wheatgrass, and with sufficient moisture good yields have been obtained from stands 10 to 15 years old. It has the ability to grow at a lower temperature than most other grasses and, depending upon the season, starts to grow from 5 to 14 days earlier than bromegrass or slender wheatgrass. Likewise it continues to grow later in the fall, and if it is used in conjunction with some grass that is more productive during the heat of midsummer, when crested wheatgrass makes little growth, the grazing season is prolonged. When moisture conditions are favorable in the fall, growth is resumed, and often a height of 6 to 8 inches is attained. This growth may best be utilized for grazing.

Like slender wheatgrass, crested wheatgrass belongs to the bunch grasses, differing in this respect from bromegrass and western wheat-

grass, both of which spread by underground rootstocks and tend to develop a uniform turf. This difference in growth tends to make western wheatgrass and bromegrass somewhat more difficult to eradicate than crested wheatgrass. In thin seedings of crested wheatgrass the individual plants tend to enlarge, and a rough and bunchy condition results in old fields, especially where there is much soil blowing.

FIGURE 1.—Typical plant of crested wheatgrass (*Agropyron cristatum*)

There is usually a marked variation in the individual plants from commercial lots of seed. This variation may be in color and size of plant, fineness and number of stems, number and distribution of leaves, hairiness of the entire plant, shape and size of seed head, and length of awn. The seeds of some plants have pronounced awns, whereas those of others have very short awns or none at all. Seeds with long

curled awns are objectionable, since they have a tendency to hang together and will not shake readily through the sieves of the thresher or fanning mill and do not feed freely through a grain drill. A fair standard for crested-wheatgrass seed is a bushel weight of 22 pounds, purity of 88 to 90 per cent, and germination of 90 per cent. This standard is not difficult to attain if care is used in handling the crop, if it is threshed without exposure to a long rainy period, and if the seed is thoroughly cleaned. When stored in a cool dry place the seed retains its viability for three or more years, with only a gradual decline in ability to germinate. There are about 250,000 to 300,000 seeds of crested wheatgrass in a pound, which is about twice as many as in a pound of slender wheatgrass.

The wide variation in the individual plants affords an excellent opportunity for improvement through breeding and selection.

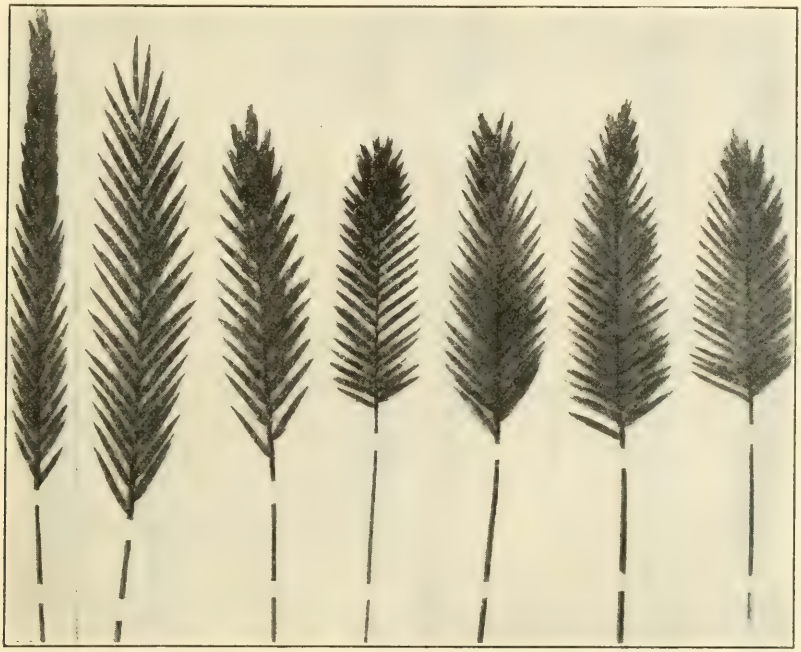

FIGURE 2.—Some of the common types of heads of crested wheatgrass

ADAPTATION

Crested wheatgrass seems especially adapted to the northern Great Plains, where the temperatures are severe and the moisture supply is limited. In parts of eastern Oregon and Washington where dry farming is practiced, crested wheatgrass is grown successfully, and it has given good yields under irrigation as far south as Garden City, Kans. It has also been reported as doing well under irrigation at Alturas, Calif. No instance is known of crested wheatgrass being killed out by severe drought or cold. It has survived the most severe droughts of the northern Great Plains, but the grass is not productive during extreme heat or drought. Under such conditions it remains dormant until the fall rains come, when growth starts again, and if moisture conditions continue favorable, considerable fall grazing is furnished.

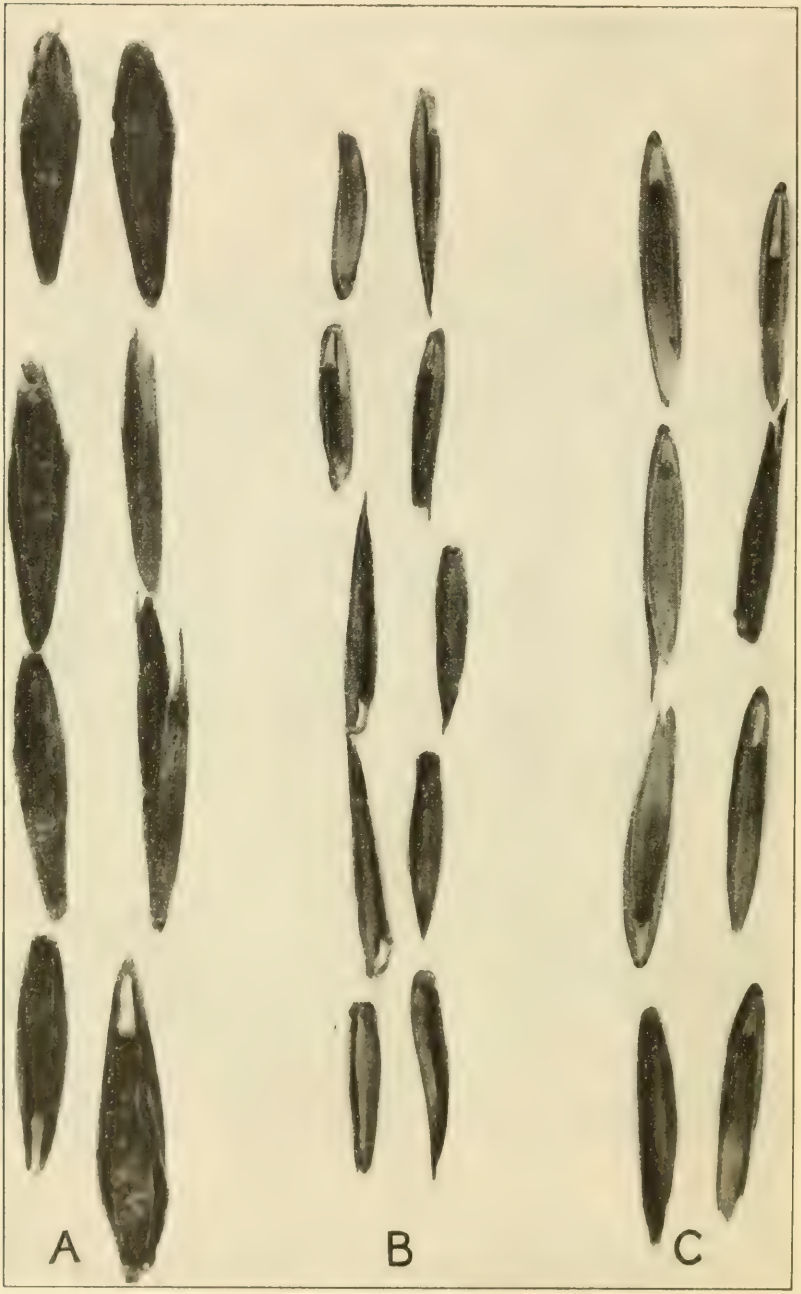

FIGURE 3.—A, Seed of bromegrass; B, seed of crested wheatgrass; C, seed of slender wheatgrass. All × 4

According to Dillman (3), 853 pounds of water is required to produce 1 pound of dry matter in crested wheatgrass, as compared with 784 pounds for bromegrass and 1,183 pounds for western wheatgrass. Dillman (3, *p. 236*) says:

> These values are probably too high as compared with the real efficiency of the grasses as dry-land crops. All are perennials, and during late summer under normal conditions they store organic food material in their rhizomes and roots which enables them to produce an early summer crop the following year with probably an efficient use of water.

This comment seems justified, since the results given in Table 19 show that 45 per cent of the season's growth of crested wheatgrass had been harvested on May 10, whereas the studies of the water requirement began on May 21 and 24, respectively, in the two years covered by these studies.

The average weighted mean water requirement of alfalfa (*Medicago sativa* L.) in these investigations was found to be 798 pounds.

While the grass withstands drought well, it also responds to favorable moisture. The largest yield ever secured at Redfield, S. Dak., about 3 tons to the acre, was obtained during a season with abundant moisture.

Crested wheatgrass does well on productive soil of almost any texture and has given good results on rather light sandy soils as well as on clay soils.

CULTURE

SEED BED

Crested wheatgrass, being tender in the seedling stage, requires the best possible conditions for germination and early growth. A firm, fine seed bed well supplied with moisture and comparatively free from weeds is essential to a satisfactory stand. This condition is generally obtained without difficulty following a crop of corn or after summer fallow. Where the moisture supply is more favorable a good seed bed may be prepared on fall or spring plowed grain stubble. The land should be worked down well, smoothed with a spike-tooth harrow, and packed, if necessary, just before seeding.

TIME OF SEEDING

The most favorable time to sow crested wheatgrass varies with the locality and the season. The usual practice is to sow in the spring at about the time of sowing spring wheat, as the moisture conditions are likely to be most favorable at that time. If the soil is dry in early spring, delayed seeding often gives better results. Likewise, where weeds are abundant, better stands result from seedings made late enough to permit two or three cultivations with a disk harrow, a spring-tooth harrow, or a duck-foot cultivator before seeding, thus killing many of the weeds. In most of the region to which the grass is suited even delayed seedings ordinarily should be made not later than the first of June. At Havre, Mont., however, the best results on an average have been secured from seedings made about June 1; though, depending upon the season, earlier and later seedings sometimes have been more successful. While spring seedings are much to be preferred, fall seedings sometimes give good results where the moisture conditions are favorable. In the vicinity of Waterville, Wash., fall seedings have generally proved more satisfactory than spring seedings. In this region it is generally advised that the seed be drilled

in grain stubble, which tends to check soil blowing during the winter. In the northern Great Plains fall seedings should be made not later than the early part of September. Fall seedings, however, are sometimes seriously injured by cold or dry weather or by grasshoppers.

EXPERIMENTS AT HAVRE, MONT.

The date-of-seeding experiments with crested wheatgrass, slender wheatgrass, and bromegrass at the Northern Montana Branch Station, Havre, Mont., included four approximate dates: April 15, May 10, June 1, and June 20. If stands the following spring are taken as an indication of the best range of dates, irrespective of method, in which to sow grasses at Havre, seven years of stand estimates summarized in Table 1 suggest that May 10 to June 1 is the most reliable period for establishing stands. However, the most favorable date has varied from year to year and has depended somewhat on the surface moisture present when the seeding was done. Very early seedings often have suffered from severe competition with weeds, and the late June seedings have been handicapped by hot, dry weather during the seedling stage. If the land has been properly prepared and the weeds destroyed, usually it is possible to select a time after May 10 when conditions favor rapid germination and satisfactory stands. Stands of grasses have been obtained from autumn seedings, but weed infestation the next year similar to that experienced from early spring seeding has rendered fall plantings less dependable than those made during the May 10 to June 1 period. Bromegrass has proved the most difficult of the three to establish, though thin stands frequently have improved materially by the end of three or four seasons. Crested wheatgrass and slender wheatgrass have appeared nearly equal with respect to the ease with which stands may be established.

TABLE 1.—*Average stands, the spring after seeding, of crested wheatgrass, slender wheatgrass, and bromegrass seeded at different times at the Northern Montana Branch Station, Havre, Mont., 1924–1931* [1]

Kind of grass	Method of seeding	Stand from sowings made approximately on—				Average
		Apr. 15	May 10	June 1	June 20	
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Crested wheatgrass	Rows	59	66	52	57	58.5
Do	Close drills	70	79	63	60	68.0
Slender wheatgrass	Rows	57	61	70	59	61.8
Do	Close drills	62	83	77	59	70.3
Bromegrass	Rows	39	50	52	50	47.8
Do	Close drills	57	84	69	56	66.5
Average		57.3	70.5	63.8	56.8	62.1

[1] 1929 data omitted in compiling the averages.

METHOD OF SEEDING

Crested wheatgrass may be sown in close drills or in rows wide enough apart to cultivate. Where the crop is to be utilized for hay or pasture, close drills are preferable, except where the moisture supply is very limited. The seed should be sown with a grain drill covering about one-half inch. Deep covering is often responsible for failure to obtain a satisfactory stand. The double-disk drill is preferable to

the single-disk drill, as it does not cover so deeply. Well-cleaned seed will run through the drill more freely than seed of most other grasses, but it is advisable to watch closely to see that none of the cups or spouts become clogged, thus leaving skips in the field.

FIGURE 4.—Crested wheatgrass under dry-land conditions at the Dickinson (N. Dak.) Substation, grown in rows for hay and seed production: A, Bloom stage, June 30, 1930; B, growth under double-row method of seeding, with thick stand of volunteer seedlings between the rows, a characteristic condition after early fall rains. Photographed October 14

Under dry-land conditions crested wheatgrass should be sown alone, although where the moisture is favorable good stands are obtained when it is sown with a nurse crop of wheat or oats. There are two ways of seeding the grass in rows, the single-row and the double-row method. (Figs. 4 and 5.) In the single-row method seed

is dropped in a row from one spout of the grain drill, and in the double-row method the seed is dropped from two adjacent spouts which are usually 6 or 7 inches apart. Both methods have been used at the United States Northern Great Plains Field Station, Mandan, N. Dak., for a number of years, but the double-row method first tried at this station in 1921 is preferred, since skips are not likely to occur. The most satisfactory distance between rows is 36 to 42 inches for either single or double rows.

If the grass is to be grown mainly for seed, it should be sown in rows and kept cultivated, as in most seasons a better quality of seed can be produced in rows than in close drills. The grass may be grown in rows for hay in areas where the rainfall is very limited, but under most conditions it is better to sow in close drills for hay or pasture. Hay produced in rows is likely to contain considerable dust and dirt, and the difference in hay yield in favor of the rows usually is not enough to offset the poorer quality of the hay and the extra work involved in keeping the rows cleanly cultivated.

EXPERIMENTS AT MOCCASIN, MONT.

Seedings of crested wheatgrass have been made yearly since 1921 at the Judith Basin branch station, Moccasin, Mont., comparing (1) rows with close drills, (2) seedings without a nurse crop with those having nurse crops of wheat or flax, and (3) seedings on fallow with those made on spring-plowed grain stubble. The results are given in Table 2.

TABLE 2.—*Annual and average acre yields of air-dry hay of crested wheatgrass produced under stated methods of seeding at the Judith Basin Branch Station, Moccasin, Mont., 1921–1930*

Method of seeding	Nurse crop	Year sown	Acre yield (pounds) of air-dry hay in—									Average
			1922	1923	1924	1925	1926	1927	1928	1929	1930	
36-inch rows on fallow	None	1921 [1]	1,980	2,180	3,472	2,156	1,731	3,430	2,120	.....	.....	2,438
Close drilled on fallow	...do...	1921 [1]	2,717	2,380	2,708	1,367	1,167	3,253	1,827	.....	.	2,200
Do	Wheat	1921	2,250	2,277	2,377	1,337	1,125	2,807	1,567	. .	...	1,963
Close drilled on spring plowing.	None	1922	.....	1,885	2,730	1,484	1,196	3,105	1,610	.....		2,002
Close drilled on fallow	do	1922		1,495	2,079	1,466	1,282	3,240	1,760	.....	.. .	1,887
Close drilled on spring plowing.	...do...	1923		.....	2,435	1,129	928	2,670	1,210	...	. .	1,674
Close drilled on fallow	...do...	1923			3,415	1,418	1,269	3,220	1,260	.....	.....	2,116
Do	Wheat	1923			3,202	1,331	1,047	2,593	1,272	...		1,889
Do	None	1925			.....	.....	2,036	4,629	2,251	1,845	1,019	2,362
Do	Wheat	1925			.....	.....	1,590	3,088	2,439	1,721	1,191	2,006
Do	Flax	1925			.....	.....	1,586	4,644	2,263	1,485	990	2,194
Do	Wheat	1926				.....	.....	3,583	2,894	1,414	1,272	2,291
Do	Flax	1926				.	.....	4,997	2,546	1,296	919	2,440
Close drilled on spring plowing.	None	1926					. .	3,064	2,946	1,697	1,161	2,217
Do	Wheat	1926						2,121	2,781	1,838	1,179	1,980
Do	Flax	1926						2,168	2,970	1,838	1,232	2,052
Close drilled on fallow	None	1927						. .	2,511	1,509	1,066	1,695
Do	Wheat	1927							2,051	1,150	1,037	1,513
Do	Flax	1927							2,298	1,544	1,073	1,638
Do	None	1928								2,239	1,627	1,933
Do	Wheat	1928								1,391	1,250	1,321
Do	Flax	1928								2,546	1,697	2,122
Close drilled on spring plowing.	...do...	1928								1,226	1,061	1,144

[1] Average yield of 3 P. I. (Foreign Plant Introduction) numbers.

In summarizing the results of these tests, it is found that crested wheatgrass in rows has given slightly higher average yields than in close drills in the one comparable test; seedings made on summer

fallow have generally averaged more than those on spring-plowed stubble, with the advantage mainly due to yields the first year; and somewhat better yields have usually resulted from seedings made without a nurse crop. In comparing flax and wheat as nurse crops, it is found the flax has had a somewhat less depressing effect on subsequent yields. In some cases where flax has been used as a nurse crop, yields have practically equaled and at times exceeded those made without a nurse crop.

EXPERIMENTS AT SHERIDAN, WYO.

Experiments at the United States Dry Land Field Station, Sheridan, Wyo., have included comparisons of seedings in close drills without a nurse crop with those having a nurse crop of barley. The yields are given in Table 3. The first year after seeding, the plots sown without a nurse crop have usually given slightly higher yields, though occasionally the advantage is in favor of seedings made with a nurse crop. No significant differences have occurred in the average yields under the two methods.

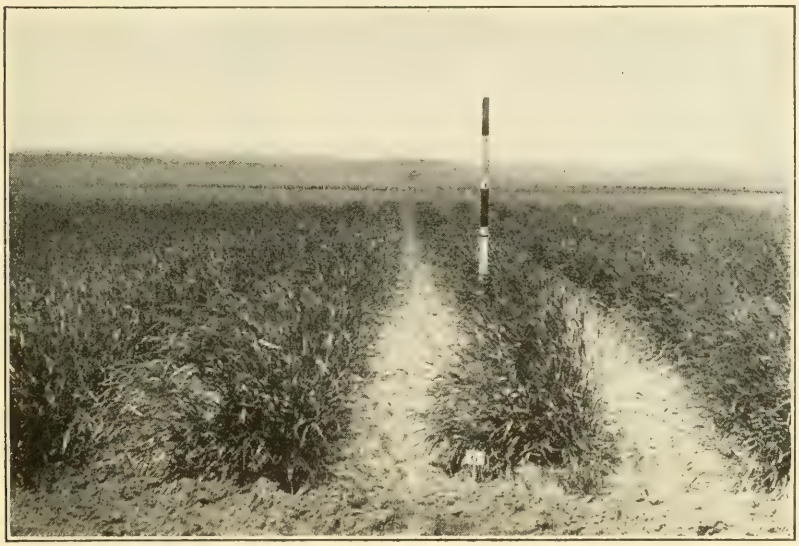

FIGURE 5.—Crested wheatgrass sown in single rows in the spring of 1922 at the United States Northern Great Plains Field Station, Mandan, N. Dak. Photographed July 1, 1924

TABLE 3.—*Annual and average acre yields of air-dry hay of crested wheatgrass sown in close drills without a nurse crop and with one of barley at the United States Dry Land Field Station, Sheridan, Wyo., 1925–1930*

Nurse crop	Year sown	Acre-yield (pounds) of air-dry hay in—						Average
		1925	1926	1927	1928	1929	1930	
None	1924	1,680	1,840	1,960	(1)	1,600	720	1,560
Barley	1924	1,400	1,400	1,720	(1)	1,520	880	1,384
None	1926			1,560	2,640	3,080	880	2,040
Barley	1926			1,840	3,240	3,080	1,040	2,300
None	1927				2,240	2,520	1,040	1,933
Barley	1927				1,920	2,200	920	1,680
None	1928					3,000	1,640	2,320
Barley	1928					2,600	1,640	2,120

[1] No data available. Not considered in averages.

RATE OF SEEDING

For hay and pasture, crested wheatgrass ordinarily should be sown in close drills at the rate of 10 to 12 pounds to the acre. (Fig. 6.) Heavier seedings result in decreased yields where the moisture supply is limited. Where the grass is to be grown in cultivated rows for seed production or for hay in the drier areas, 2 to 3 pounds of seed per acre is ample for single rows and 4 to 5 pounds for double rows 42 inches apart. In close-drilled seedings the grain drill should be set for about one-half the usual rate of seeding wheat. If the seed is clean and heavy it may be necessary to close the drill, but if the seed does not feed readily the drill must be opened wider. All that is necessary is to keep the seed dropping. The drill cups should be watched to

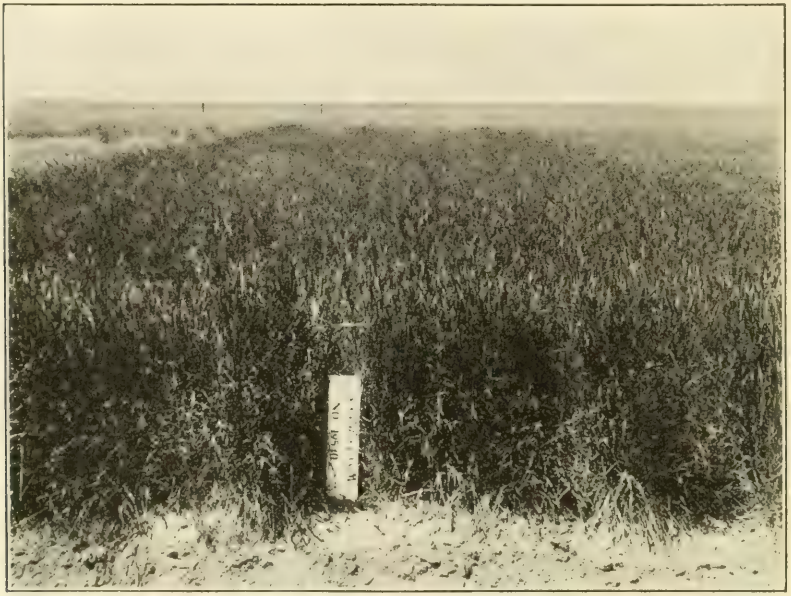

FIGURE 6.—A close-drilled plot of crested wheatgrass at the Judith Basin Branch Station, Moccasin, Mont.

see that they do not clog. The drill box should be filled about one-third, and the seed should be leveled off with the hand at frequent intervals.

CULTIVATION

Ordinarily a close-drilled field of crested wheatgrass does not require any attention during the year that it is sown. In case of a favorable season a light hay crop may be obtained, but usually there is not enough growth to pay for the trouble of harvesting. If weeds become very troublesome the field may be clipped, although ordinarily it is better not to mow during the year of seeding, as there is some advantage in allowing the grass and weeds to stand to catch the snow during the winter. Furthermore, if the stand happens to be rather thin, enough of the plants may produce seed when not cut the first season to thicken the stand materially. Where there is an abundance of weeds the field should be burned on a windy day in the spring following seeding before the new growth starts; or if this is not feasible, the weeds

should be raked and hauled off for burning. It is not advisable to burn the bunches on the field, as the grass under them is sure to be killed. After the first year, weeds give little trouble in a close-drilled field. When the grass is sown in rows it is advisable to cultivate the first season to keep down weeds between the rows, but the weeds in the rows may be left, as they help to catch the snow and so furnish protection for the plants during the winter. After the first year the rows need cultivating two or three times a season. In old stands weeds sometimes become troublesome in the rows and may require some attention.

COMPOSITION

EXPERIMENTS AT DICKINSON, N. DAK.

The composition of crested wheatgrass at various stages of growth as compared with slender wheatgrass, bromegrass, and native grasses grown on similar soils is shown in Table 4. In all cases the analyses are based on hay containing 15 per cent moisture. In this study, made at the Dickinson Substation, Dickinson, N. Dak., crested wheatgrass and bromegrass started to head about May 20 to 25, and slender wheatgrass started about 10 days later. Crested wheatgrass and bromegrass were starting to bloom June 25, while the slender wheatgrass was still heading. On July 25 crested wheatgrass was beginning to mature and was somewhat ahead of the bromegrass. Crested wheatgrass and bromegrass were mature on August 10, and the slender wheatgrass was shattering. Although it headed somewhat later than the other species, slender wheatgrass matured more rapidly.

TABLE 4.—*Composition of crested wheatgrass, slender wheatgrass, bromegrass, and native grasses at various stages of growth from early spring to full maturity at the Dickinson Substation, Dickinson, N. Dak., 1928* [1]

[Data calculated in percentages on the basis of hay containing 15 per cent moisture]

Date cut	Ash				Ether extract				Crude protein				Crude fiber			
	Crested wheatgrass	Slender wheatgrass	Bromegrass	Native grasses	Crested wheatgrass	Slender wheatgrass	Bromegrass	Native grasses	Crested wheatgrass	Slender wheatgrass	Bromegrass	Native grasses	Crested wheatgrass	Slender wheatgrass	Bromegrass	Native grasses
Apr. 10	8.84	9.30	10.18	----	2.01	1.28	1.51	----	15.86	9.68	11.02	----	27.39	31.78	27.00	----
Apr. 25	9.46	9.49	8.98	----	2.01	1.59	1.99	----	19.07	11.00	13.23	----	22.94	29.50	24.17	----
May 10	10.25	12.10	11.87	----	3.10	2.71	2.75	----	21.01	15.73	18.51	----	21.16	24.62	20.43	----
May 25	8.02	8.92	10.83	7.47	2.64	3.52	2.87	2.06	18.82	18.11	19.93	11.87	22.92	22.74	19.71	23.71
June 10	5.47	6.60	6.14	----	2.48	2.84	2.43	----	12.27	12.95	14.57	----	26.94	24.28	22.89	----
June 25	4.79	6.32	9.96	9.46	2.44	2.55	2.24	1.71	12.61	12.61	11.94	18.70	25.52	25.97	22.92	23.66
July 10	5.59	7.86	8.05	----	1.90	1.92	2.20	----	9.76	9.93	11.68	----	25.81	29.38	26.63	----
July 25	5.49	5.64	5.71	7.80	2.16	1.92	1.97	2.15	9.78	8.72	9.20	9.66	25.43	28.79	24.80	25.28
Aug. 10	5.25	5.81	6.14	----	2.27	2.12	2.18	----	9.05	6.31	8.98	----	25.61	30.27	21.37	----
Aug. 25	----	----	----	10.12	----	----	----	1.61	----	----	----	8.19	----	----	----	23.59
Average	7.02	8.00	8.65	----	2.33	2.27	2.24	----	14.25	11.67	13.23	----	24.86	27.48	23.32	----

[1] The analyses were made by the Department of Agricultural Chemistry, North Dakota Agricultural Experiment Station, and in part published by that station (*8*).

As is shown in Table 4, the ash content of crested wheatgrass, with a few minor exceptions, is lower than that of bromegrass, slender wheatgrass, or native grasses for most stages of growth. Ether extract is not of great significance in grasses, as all are relatively low in fat, but in the analyses here reported crested wheatgrass had a higher

percentage of ether extract than slender wheatgrass or bromegrass on five of the nine harvesting dates, and the average for the season was also slightly higher. The crude-protein content of crested wheatgrass early in the season was considerably greater than that of the other grasses, reaching its maximum on May 10, after which there was a gradual decline as the grass approached maturity. Slender wheatgrass and bromegrass reached their maximum protein content May 25, and the native grasses June 25. Slender wheatgrass exceeded crested wheatgrass in protein in only two of the nine dates of harvesting. In the average of all analyses the protein content of crested wheatgrass was more than that of slender wheatgrass or of bromegrass. The crude-fiber content of a grass is indicative of its digestibility and palatability; the lower the crude fiber the greater the palatability, other factors being equal. The data given in Table 4 show that crested wheatgrass is appreciably superior to slender wheatgrass in this respect, but not quite so good as bromegrass.

At the Dickinson substation plots of crested wheatgrass, slender wheatgrass, and bromegrass were clipped twice monthly from April 10 to September 25. Analyses of these clippings are given in Table 5. It is believed that these analyses are indicative of the composition of the grasses as grazed during the season. It will be noted that there is a considerable range in the composition at different periods but that there are no consistent or very striking differences in the three grasses when cut at semimonthly intervals. The highest protein content shown is 28.73 per cent for crested wheatgrass on June 25. This, however, is only slightly higher than the 28.03 per cent of bromegrass on September 10. Similarly, the average of all clippings shows a somewhat higher protein content for the crested wheatgrass than for slender wheatgrass or bromegrass, and a lower crude-fiber content for bromegrass than for the other two grasses. The protein content is higher than would be found in ordinary pasture clippings, since the grasses from which the samples were taken were grown in rows; but it is believed that the analyses of the three grasses are comparable.

TABLE 5.—*Composition of clippings of crested wheatgrass, slender wheatgrass, and bromegrass clipped semimonthly from April 10 to September 25, 1928, at the Dickinson Substation, Dickinson, N. Dak.*[1]

[Data calculated in percentages on the basis of hay containing 15 per cent moisture]

Date cut	Ash			Ether extract			Crude protein			Crude fiber		
	Crested wheatgrass	Slender wheatgrass	Bromegrass	Crested wheatgrass	Slender wheatgrass	Bromegrass	Crested wheatgrass	Slender wheatgrass	Bromegrass	Crested wheatgrass	Slender wheatgrass	Bromegrass
Apr. 10	8.84	9.30	10.18	2.01	1.28	1.51	15.86	9.68	11.02	27.39	31.78	27.00
Apr. 25	9.61	9.38	9.46	2.72	2.61	2.64	25.16	23.32	22.36	19.45	19.30	16.97
May 10	9.95	10.68	11.53	4.47	3.96	4.07	27.43	27.21	26.49	18.54	17.50	16.37
May 25	9.44	9.15	10.87	2.44	3.47	3.17	24.79	24.54	24.61	20.97	20.39	19.38
June 10	8.64	8.43	7.93	1.79	2.88	2.39	21.88	21.59	22.87	21.20	20.26	20.71
June 25	10.27	10.34	18.89	2.65	2.06	2.29	28.73	23.72	23.31	19.92	20.42	17.60
July 10	19.12	16.86	21.60	2.31	3.35	2.40	20.88	24.16	20.36	19.77	17.73	18.28
July 25	10.89	10.35	10.62	2.84	3.52	3.45	27.87	21.25	22.86	18.98	20.86	19.08
Aug. 10	9.51	8.63	11.08	3.20	3.14	2.98	24.24	18.90	22.98	13.99	22.48	17.09
Aug. 25	9.68	10.03	7.93	3.49	3.32	2.98	24.51	18.73	26.19	18.02	21.44	15.47
Sept. 10	8.54	8.37	8.50	3.77	4.35	2.67	25.91	20.95	28.03	18.34	19.79	15.87
Sept. 25	9.81	9.57	8.49	3.42	3.09	3.45	24.75	22.18	24.76	17.97	18.41	14.95
Average	10.36	10.09	11.42	2.93	3.09	2.83	24.33	21.35	22.99	19.55	20.86	18.23

[1] See footnote to Table 4.

The difference in protein content between crested wheatgrass grown in rows and that grown in close drills is given in Table 6. On each of the several dates crested wheatgrass grown in rows contained appreciably more protein than when grown in close drills. This difference is probably the result of the more rapid growth of the grass in rows, due to a more favorable moisture supply and also to more available nitrogen in the cultivated soil.

TABLE 6.—*Crude-protein content of crested wheatgrass clipped at monthly intervals as affected by the method of seeding, at the Dickinson Substation, Dickinson, N. Dak., 1928* [1]

Method of seeding	Percentage of crude protein when clipped on—				
	Apr. 25	May 25	June 25	July 25	Average
Rows	25.16	24.79	28.73	27.87	26.64
Close drills	20.11	21.69	23.83	18.13	20.94
Difference in favor of rows	5.05	3.10	4.90	9.74	5.70

[1] See footnote to Table 4.

EXPERIMENTS AT MANDAN, N. DAK.

The chemical composition of crested wheatgrass, slender wheatgrass, and western-wheatgrass hay collected at the field station at Mandan, N. Dak., is given in Table 7. These samples were taken at practically the same stage of growth. It will be noted that the protein content of crested wheatgrass is twice that of slender wheatgrass but only slightly more than that of western wheatgrass.

TABLE 7.—*Chemical composition of grasses collected at the United States Northern Great Plains Field Station, Mandan, N. Dak.*[1]

Kind of grass	Dry matter	Percentage composition of dry matter				
		Ash	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract
Crested wheatgrass [2]	95.61	9.98	13.95	1.52	38.99	35.56
Slender wheatgrass [3]	95.24	7.56	6.76	1.44	42.82	41.42
Western wheatgrass [4]	94.56	7.82	12.69	1.74	36.48	41.26
Slender-wheatgrass seed [5]	95.57	6.26	7.16	2.44	32.12	52.02
Western-wheatgrass seed [6]	95.40	6.31	13.95	1.87	22.79	55.08

[1] Analyses made by T. H. Hopper, agricultural chemist, North Dakota Agricultural Experiment Station.
[2] Cut July 8, 1924. Plants just coming into bloom. Season later than usual.
[3] Cut July 10, 1924. Plants in full bloom.
[4] Cut July 9, 1924. Plants in full bloom.
[5] Seed picked Aug. 25, 1924. Fully mature.
[6] Seed picked Aug. 24, 1924. Fully mature.

Table 7 also gives the analyses of seeds of slender wheatgrass and western wheatgrass, but no analyses were made of crested-wheatgrass seed. The protein content of slender-wheatgrass seed is only about one-half that of western wheatgrass, the relation being similar to that found in the hay.

UTILIZATION

Crested wheatgrass makes a very palatable hay, is a good pasture grass, has been used successfully in the improvement of ranges and in reseeding abandoned plowed areas, and under some conditions may be utilized to advantage on lawns. It is also valuable as a sod crop in a rotation with flax or other crops.

AS A HAY CROP

So far as quality and palatability are concerned, crested-wheatgrass hay compares most favorably with the famous western-wheatgrass hay of certain parts of the Great Plains. While crested wheatgrass is readily eaten by all classes of livestock, horses seem to be especially fond of the hay, often preferring it to bromegrass hay. In the United States forage-crop field experiments at Redfield, S. Dak., horses have eaten the crested-wheatgrass straw in preference to good bromegrass hay.

Kirk (*9*) says:

> This year [1927] crested wheat grass straw was compared with western rye grass [slender wheatgrass] hay by placing a forkful of each before several horses in the barn. Invariably the crested wheat grass straw was completely eaten first. This speaks well for the palatability of crested wheat grass and emphasizes the excellent quality of the feed after the seed has been removed by threshing.

The stems of crested wheatgrass are generally fine, leaves medium abundant, and both stems and leaves retain their green color remarkably well. To obtain the best quality of hay, crested wheatgrass should be cut shortly after it comes into bloom. In the northern Great Plains this time varies with the season but will usually be the latter part of June or early July. The hay cures readily and may be hauled in soon after cutting. Over a period of years crested wheatgrass has outyielded other cultivated grasses grown in the region. Both bromegrass and slender wheatgrass frequently give better yields the first two or three years, after which the bromegrass tends to become sod bound, resulting in decreased yields, and the yields of slender wheatgrass decline, owing to a natural thinning out of the grass, which is shorter lived than either crested wheatgrass or bromegrass. Plots of crested wheatgrass that have been down 10 years or more have given some remarkable yields in seasons of sufficient moisture.

EXPERIMENTS AT MANDAN, N. DAK.[6]

The first seeding of crested wheatgrass at the field station at Mandan, N. Dak., was made in 42-inch single rows in 1915. (Fig. 7.) Bromegrass and slender wheatgrass were sown at the same time and in the same manner. Bromegrass was also sown in close-drilled plots. (Fig. 8.) Yields of hay have been secured from these seedings of crested wheatgrass and bromegrass each year since 1916, but the slender wheatgrass was completely killed in the winter of 1919–20. The results are shown in Table 8. In these early seedings bromegrass in rows outyielded crested wheatgrass in rows only twice, and the close-drilled plots of bromegrass produced more hay than crested wheatgrass in rows in only three seasons. The 1922 seedings of

[6] From 1915 to 1922 these investigations were carried on cooperatively between the offices of Dry Land Agriculture and Alkali and Drought-Resistant Plant Investigations of the U. S. Department of Agriculture, under the supervision of A. C. Dillman. Since 1922 the Division of Dry Land Agriculture and the Division of Forage Crops and Diseases have cooperated in the forage-crop investigations at Mandan.

crested wheatgrass in rows produced as much or more hay each year than bromegrass in rows or close drills.

TABLE 8.—*Annual and average acre yields of air-dry hay of crested wheatgrass, slender wheatgrass, and bromegrass grown for different periods during the years 1916–1930 at the United States Northern Great Plains Field Station, Mandan, N. Dak.*[1]

Kind of grass	Method of seeding	Year sown	Acre yield (pounds) of air-dry hay in—							
			1916	1917	1918	1919	1920	1921	1922	1923
Crested wheatgrass	Rows	1915	3,550	3,200	3,200	3,080	1,250	1,850	1,900	1,225
	do	1922								
Slender wheatgrass	Rows	1915	4,550	3,000	1,800	1,510	[2]			
	do	1923								
	Close drills	1923								
	do	1927[3]								
Bromegrass	Rows	1915	[4] 4,980	[4] 2,910	[4] 2,490	[4] 2,120	[4] 470	[4] 1,240	[5] 1,575	[5] 1,070
	do	1922								
	Close drills	1915	4,900	1,350	1,450	1,500	440	1,800	[5] 1,600	[5] 778
	do	1923								

Kind of grass	Method of seeding	Year sown	Acre yield (pounds) of air-dry hay in—							Average
			1924	1925	1926	1927	1928	1929	1930	
Crested wheatgrass	Rows	1915	2,505	1,040	507	1,650	707	1,367	1,956	1,932
	do	1922	3,770	1,770	695	2,003	1,532	1,815	2,003	1,941
Slender wheatgrass	Rows	1915								
	do	1923	2,845	1,716	248	1,816	1,650	1,933	1,061	1,610
	Close drills	1923	3,105	1,276	0	1,953	[6] 0	[7]		1,267
	do	1927[3]						1,045	550	798
Bromegrass	Rows	1915	[5] 1,583	[5] 675	0	1,250	1,532	[5] 884	[5] 1,438	1,614
	do	1922	2,335	958	200	1,461	1,532	707	1,626	1,260
	Close drills	1915	[5] 1,380	[5] 650	316	2,173	1,375	275	935	1,395
	do	1923	2,090	743	138	1,788	1,238	275	1,073	1,049

[1] Yield from single plot unless otherwise noted.
[2] Killed out during preceding winter.
[3] Poor stand in 1928.
[4] Average of 4 plots.
[5] Average of 2 plots.
[6] Grass practically dead on this plot.
[7] Grass dead.

Slender wheatgrass outyielded crested wheatgrass once in the 1915 seedings and twice in the later seedings. After the 1915 seeding was killed, a satisfactory stand of slender wheatgrass was not again obtained until the reseeding in 1923. A good stand of crested wheatgrass was obtained in 1922, but slender wheatgrass failed to catch and was reseeded in 1923. A yield of 1,820 pounds per acre of crested wheatgrass was obtained in 1923 from the 1922 seeding but is not given in the table, as no hay was obtained from slender wheatgrass that year. It will be noted that during the period 1924–1930 the newer seeding of crested wheatgrass yielded more than the older seeding by an average of about 550 pounds per acre annually. These results indicate that the highest yields are often secured the first or second year after seeding and that with favorable moisture conditions the grass will continue to produce good crops of hay for many years. The seeding of crested wheatgrass made in 1915 gave the sixth best yield in 1930, the fifteenth year. In this locality crested wheatgrass forms seed heads during the early part of June and is ready to cut for hay during the latter part of June or early July.

EXPERIMENTS AT DICKINSON, N. DAK.

The first recorded seeding of crested wheatgrass at the Dickinson substation was made in 1909 with seed imported in 1908, but no yields are available from this seeding. The seed for the plots from which hay yields were first obtained was furnished by the Division of Forage Crops and Diseases, United States Department of Agriculture, and was sown in rows and close drills in the spring of 1920. The hay yields from these seedings as well as from seedings made in rows and close drills in 1926 are shown in Table 9.

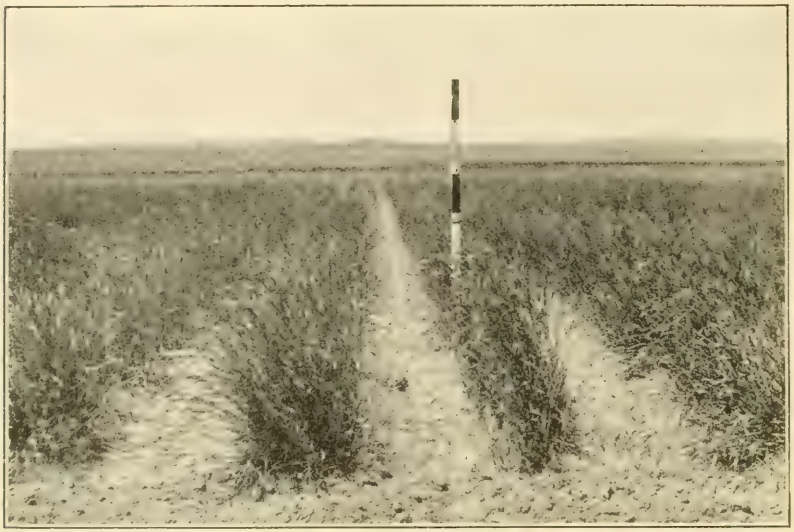

FIGURE 7.—Crested wheatgrass sown in 1915 in single rows at the United States Northern Great Plains Field Station, Mandan, N. Dak. This is apparently the oldest seeding still producing in the United States (1932). Photographed July 1, 1924

TABLE 9.—*Annual and average acre yields of air-dry hay of crested wheatgrass, slender wheatgrass, and bromegrass at the Dickinson Substation, Dickinson, N. Dak., 1921–1930*

Kind of grass	Method of seeding	Year sown	Acre yield (pounds) of air-dry hay in—										Average
			1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	
Crested wheatgrass	Rows	1920	412	1,659	1,583	2,365	1,797	1,218	2,581	----	----	----	1,659
	Close drills	1920	660	2,355	1,518	2,146	1,823	804	2,208	----	----	----	1,645
Slender wheatgrass	Rows	1920	673	1,326	1,806	1,394	1,669	411	33	----	----	----	1,045
	Close drills	1920	758	3,069	2,819	1,813	1,716	437	241	----	----	.	1,550
Bromegrass	Rows	1920	764	2,240	2,406	2,943	2,120	709	2,092	----	----	----	1,896
	Close drills	1920	665	2,276	2,213	2,604	2,304	370	1,177	----	----	----	1,658
Crested wheatgrass	Rows	1926	----	----	----	----	----	----	1,331	2,182	2,977	2,306	2,199
	Close drills	1926	----	----	----	----	----	----	2,046	2,427	1,836	1,301	1,903
Slender wheatgrass	Rows	1926	----	----	----	----	----	----	2,713	1,679	1,677	342	1,603
	Close drills	1926	----	----	----	----	----	----	2,315	2,022	980	580	1,474
Bromegrass	Rows	1926	----	----	----	----	----	----	1,683	2,480	3,848	1,236	2,312
	Close drills	1926	----	----	----	----	----	----	2,020	1,524	800	960	1,349

In both seedings in rows the yields of bromegrass were highest, though followed rather closely by crested wheatgrass, while slender wheatgrass gave the lowest yields. In the close-drilled seedings the average yield of crested wheatgrass was slightly less than that of

bromegrass in the 1920 seeding but considerably exceeded that of both bromegrass and slender wheatgrass in the 1926 seedings, the average yield of bromegrass being the lowest.

EXPERIMENTS AT HAVRE, MONT.

The first seeding of crested wheatgrass at the Northern Montana Branch Station of the State Agricultural Experiment Station, Havre Mont., made in 1917 under dry-land conditions, failed because of an unfavorable season. Seedings made in 1918 and 1919 suffered a similar fate owing to drought. It was not until 1920 that attempts to establish this grass were successful. These and subsequent tests were planned in part to determine the productiveness of crested wheatgrass as compared with bromegrass and slender wheatgrass when sown in close drills and in 36-inch rows. Table 10 gives the annual and average hay yields from these tests.

TABLE 10.—*Annual and average acre yields of air-dry hay of crested wheatgrass, slender wheatgrass, and bromegrass at the Northern Montana Branch Station, Havre, Mont., 1921–1930*

Kind of grass	Method of seeding	Year sown	Acre yield (pounds) of air-dry hay in—										Average
			1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	
Crested wheatgrass	Rows	1920	2,400	1,860	[1]	1,355	913	497	2,995	2,489	2,352	1,341	1,800
	Close drills	1920	978	1,323	1,140	835	996	231	4,143	1,731	1,743	864	1,398
Slender wheatgrass	Rows	1920	4,380	2,118	2,990	808	[2] 1,420	260	------	------	------	------	------
	Close drills	1920	840	1,197	3,300	1,224	1,260	[2] 148	------	------	------	------	------
Bromegrass	Rows	1920	1,960	2,152	2,070	657	1,222	202	[3] 2,369	1,871	1,802	456	1,476
	Close drills	1920	559	887	1,060	920	1,080	0	2,740	1,249	1,201	350	1,005
Slender wheatgrass	Rows	1923 [4]	----	----	----	808	1,920	0	------	------	------	------	909
	Close drills	1923	----	----	----	1,763	1,747	0	------	------	------	------	1,170
Bromegrass	Rows	1923	----	----	----	337	1,813	313	------	------	------	------	821
	Close drills	1923	----	----	----	1,190	1,687	0	------	------	------	------	959
Crested wheatgrass	Rows	1924	----	----	----	----	690	742	3,854	1,440	------	------	1,682
	Close drills	1924	----	----	----	----	925	0	4,238	940	------	------	1,526
Slender wheatgrass	Rows	1924	----	----	----	----	1,045	0	4,747	2,179	------	------	1,993
	Close drills	1924	----	----	----	----	1,130	0	4,125	1,400	------	------	1,664
Bromegrass	Rows	1924	----	----	----	----	795	349	3,895	1,354	------	------	1,598
	Close drills	1924	----	----	----	----	830	0	3,786	1,311	------	------	1,482
Crested wheatgrass	Rows	1925	----	----	----	----	----	355	3,437	2,842	2,357	------	2,248
	Close drills	1925	----	----	----	----	----	565	5,111	1,649	1,529	------	2,214
Slender wheatgrass	Rows	1925	----	----	----	----	----	715	5,575	3,347	1,923	------	2,890
	Close drills	1925	----	----	----	----	----	480	5,835	1,411	877	------	2,151
Bromegrass	Rows	1925	----	----	----	----	----	0	3,348	1,803	1,462	------	1,653
	Close drills	1925	----	----	----	----	----	0	2,774	779	1,133	------	1,172
Crested wheatgrass	Rows	1926	----	----	----	----	----	----	1,694	3,854	2,935	1,496	2,495
	Close drills	1926	----	----	----	----	----	----	3,080	1,882	2,417	691	2,018
Slender wheatgrass	Rows	1926	----	----	----	----	----	----	1,081	3,783	2,438	284	1,897
	Close drills	1926	----	----	----	----	----	----	2,756	2,535	1,828	380	1,875
Bromegrass	Rows	1926	----	----	----	----	----	----	599	2,641	1,870	456	1,392
	Close drills	1926	----	----	----	----	----	----	1,677	1,463	1,454	135	1,182
Crested wheatgrass	Rows	1927	----	----	----	----	----	----	------	1,857	2,676	1,476	2,003
	Close drills	1927	----	----	----	----	----	----	------	1,843	1,831	634	1,436
Slender wheatgrass	Rows	1927	----	----	----	----	----	----	------	3,879	2,804	528	2,404
	Close drills	1927	----	----	----	----	----	----	------	1,805	1,376	288	1,156
Bromegrass	Rows	1927	----	----	----	----	----	----	------	2,877	2,632	447	1,985
	Close drills	1927	----	----	----	----	----	----	----	1,311	878	445	878
Crested wheatgrass	Rows	1928	----	----	----	----	----	----	----	------	1,312	1,373	1,343
	Close drills	1928	----	----	----	----	----	----	----	------	1,662	1,101	1,382
Slender wheatgrass	Rows	1928	----	----	----	----	----	----	----	------	2,657	920	1,789
	Close drills	1928	----	----	----	----	----	----	----	------	2,772	104	1,438
Bromegrass	Rows	1928	----	----	----	----	----	----	----	----	1,622	192	907
	Close drills	1928	----	----	----	----	----	----	----	----	1,591	490	1,041

[1] No data available.
[2] Mostly volunteer crested wheatgrass.
[3] Bromegrass plots for this and subsequent years had considerable volunteer crested wheatgrass.
[4] Yields from seedings made in 1923 and subsequent years for the most part represent averages from 4 seeding dates.

The average annual yields from the row seedings of all years were appreciably higher than from the close-drilled plots, doubtless owing to the limited seasonal rainfall normal to this area. Yields of crested wheatgrass and slender wheatgrass, regardless of the method of seeding, averaged more than those of bromegrass. Crested wheatgrass produced an average yield only slightly less than that of slender wheatgrass on the close-drilled plots, but slender wheatgrass had a greater advantage in 36-inch rows. In dry seasons such as 1926, 1928, and 1930 the yield of crested wheatgrass was generally more than that of slender wheatgrass, but in seasons when the rainfall was normal or above during the latter part of May and June, slender wheatgrass gave a higher yield than crested wheatgrass.

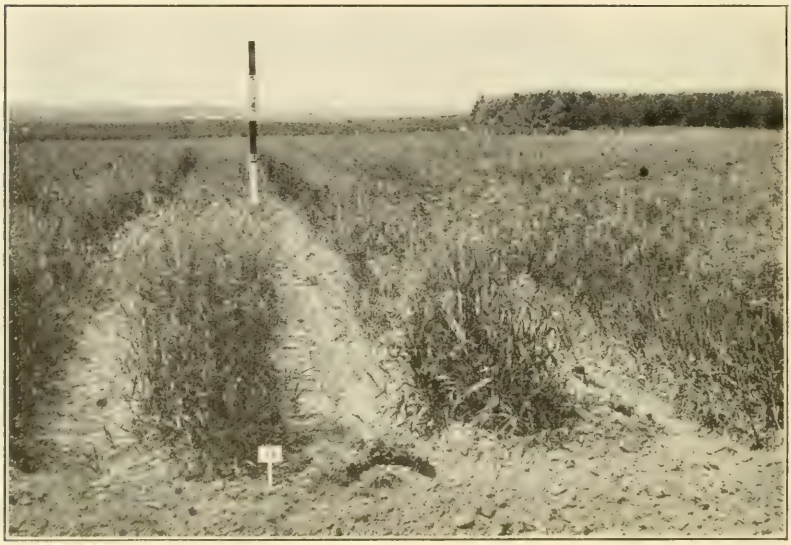

FIGURE 8.—Bromegrass sown in rows in the spring of 1915 at the United States Northern Great Plains Field Station, Mandan, N. Dak. The rows have been kept separated during the period from 1915 to 1930, inclusive, by plowing the area between and by other means of cultivation. A close-drilled plot of bromegrass is shown at the right. Photographed July 1, 1924

EXPERIMENTS AT MOCCASIN, MONT.

The first seeding of crested wheatgrass on record at the Judith Basin Branch Station, Moccasin, Mont., was made in 1915, but no yield data are available from this seeding. In 1917 three lots of crested wheatgrass and one lot each of slender wheatgrass and bromegrass were sown in close-drilled plots. Yields were obtained from these plots each year from 1918 to 1926, inclusive. Other seedings were made in 1921 and each subsequent year to 1928, with the exception of 1924. The results are shown in Table 11.

TABLE 11.—*Annual and average acre yields of air-dry hay of crested wheatgrass, slender wheatgrass, and bromegrass, at the Judith Basin Branch Station, Moccasin, Mont., 1918–1930*

Kind of grass	Method of seeding	Year sown	Acre yield (pounds) of air-dry hay in						
			1918	1919	1920	1921	1922	1923	1924
Crested wheatgrass	Close drills	1917	2,638	0	2,886	1,634	1,394	1,521	1,111
Slender wheatgrass	do	1917	2,907	0	1,144	1,851	1,002	1,808	1,006
Bromegrass	do	1917	1,768	0	2,178	2,844	1,764	1,198	1,285
Crested wheatgrass	do	1921					2,483	2,328	2,543
Do	Rows	1921					1,980	2,180	3,472
Do	Close drills	1922						1,690	2,707
Do	do	1923							2,872
Bromegrass	do	1923							3,726
Crested wheatgrass	do	1925							
Bromegrass	do	1925							
Crested wheatgrass	do	1926							
Bromegrass	do	1926							
Crested wheatgrass	do	1927							
Bromegrass	do	1927							
Crested wheatgrass	do	1928							
Bromegrass	do	1928							

Kind of grass	Method of seeding	Year sown	Acre yield (pounds) of air-dry hay in—						Average
			1925	1926	1927	1928	1929	1930	
Crested wheatgrass	Close drills	1917	605	527					1,368
Slender wheatgrass	do	1917	995	279					1,221
Bromegrass	do	1917	900	209					1,350
Crested wheatgrass	do	1921	1,336	1,146	3,020	1,697			2,079
Do	Rows	1921	2,156	1,731	3,430	2,120			2,438
Do	Close drills	1922	1,475	1,239	3,183	1,685			1,997
Do	do	1923	1,252	1,043	2,788	1,238			1,839
Bromegrass	do	1923	1,176	673	3,312	966			1,971
Crested wheatgrass	do	1925		1,737	4,120	2,318	1,684	1,077	2,187
Bromegrass	do	1925		1,007	5,029	2,329	910	408	1,937
Crested wheatgrass	do	1926			3,187	2,827	1,617	1,153	2,196
Bromegrass	do	1926			3,880	3,072	1,194	362	2,127
Crested wheatgrass	do	1927				2,287	1,501	1,059	1,616
Bromegrass	do	1927				2,294	1,375	486	1,385
Crested wheatgrass	do	1928					1,851	1,409	1,630
Bromegrass	do	1928					1,706	578	1,142

To summarize the results, the highest yield of all seedings was obtained from crested wheatgrass in rows. Bromegrass in close drills generally proved more productive than crested wheatgrass in seasons with higher precipitation, while in the drier years the yields of bromegrass were generally less than those of crested wheatgrass. The average yields with one exception were in favor of crested wheatgrass, though the differences are not significant. Both bromegrass and crested wheatgrass gave higher yields than slender wheatgrass in the one comparable seeding.

EXPERIMENTS AT SHERIDAN, WYO.

The first seeding of crested wheatgrass at the United States Dry Land Field Station, Sheridan, Wyo., was made in 1923, but no crop was harvested until 1925. The results are given in Table 12.

TABLE 12.—*Annual and average acre yields of air-dry hay of crested wheatgrass, slender wheatgrass, and bromegrass at the United States Dry Land Field Station, Sheridan, Wyo., 1925–1930*

Kind of grass	Method of seeding	Year sown	Acre yield (pounds) of air-dry hay in—						Average
			1925	1926	1927	1928	1929	1930	
Crested wheatgrass	Rows	1923	980	2,760	2,720	2,120	2,600	1,200	2,063
	Close drills	1923	1,520	3,280	2,680	2,000	2,320	640	2,073
Bromegrass	Rows	1923	3,320	2,640	2,880	1,360	1,200	0	1,900
	Close drills	1923	2,700	1,520	2,640	800	920	0	1,430
Crested wheatgrass	Rows	1924	1,640	1,680	2,160	[1]	2,400	1,000	1,776
	Close-drills	1924	1,680	1,840	1,960	[1]	1,600	720	1,560
Bromegrass	Rows	1924	760	1,160	1,920	[1]	1,200	560	1,120
	Close drills [2]	1924	720	950	1,640	[1]	1,200	360	974
Crested wheatgrass	Rows	1926			1,080	2,600	2,800	1,400	1,970
	Close drills	1926			1,560	2,640	3,080	880	2,040
Bromegrass	Rows	1926			1,200	3,240	3,200	600	2,060
	Close drills	1926			1,760	2,360	1,880	120	1,530
Crested wheatgrass	do	1927				2,240	2,520	1,040	1,933
Slender wheatgrass	do	1927				1,920	1,800	0	1,240
Bromegrass	do	1927				2,000	2,120	280	1,467
Crested wheatgrass	do	1928					3,000	1,640	2,320
Slender wheatgrass	do	1928					1,400	1,160	1,280
Bromegrass	do	1928					2,440	1,280	1,860

[1] No data available.
[2] Sown with nurse crop of barley; all other data from seedings made without a nurse crop.

Summarizing the results of all seedings, crested wheatgrass has an advantage over bromegrass, which in turn has given better results than slender wheatgrass; and while there is little difference in the average yields from rows and close-drilled seedings of crested wheatgrass, the row seedings of bromegrass have proved to be appreciably more productive than close drills.

EXPERIMENTS AT ARCHER, WYO.

The first seedings of crested wheatgrass, slender wheatgrass, and bromegrass at the Cheyenne Experiment Farm, Archer, Wyo., were made in 1917. The yields obtained from this seeding as well as from others made in 1920 and 1924 are given in Table 13. With a few exceptions the yields of all these grasses have been low, owing to a limited supply of moisture. Crested wheatgrass gave the highest average yields in the 1917 and 1920 seedings, but in the 1924 seedings slender wheatgrass had a slight advantage. Bromegrass, which was included in the 1920 and 1924 seedings, has proved less productive than either of the other grasses.

TABLE 13.—*Average and annual acre yields of air-dry hay of crested wheatgrass, slender wheatgrass, and bromegrass at the Cheyenne Experiment Farm, Archer, Wyo., 1918–1930*

Kind of grass	Method of seeding	Year sown	Acre yield (pounds) of air-dry hay in—						
			1918	1919	1920	1921	1922	1923	1924
Crested wheatgrass	Close drills	1917	4,700	1,540	1,500				
Slender wheatgrass	do	1917	3,500	620	2,000				
Crested wheatgrass	do	1920				1,000	1,110	1,140	1,000
Slender wheatgrass	do	1920				1,650	230	1,050	200
Bromegrass	do	1920				1,350	500	630	350
Crested wheatgrass	do	1924							
Slender wheatgrass	do	1924							
Bromegrass	do	1924							

TABLE 13.—*Average and annual acre yields of air-dry hay of crested wheatgrass, slender wheatgrass, and bromegrass at the Cheyenne Experiment Farm, Archer, Wyo., 1918–1930*—Continued

Kind of grass	Method of seeding	Year sown	Acre yield (pounds) of air-dry hay in—						Average
			1925	1926	1927	1928	1929	1930	
Crested wheatgrass	Close drills	1917							2,589
Slender wheatgrass	do	1917							2,040
Crested wheatgrass	do	1920	100	600					825
Slender wheatgrass	do	1920	100	920					692
Bromegrass	do	1920	50	300					530
Crested wheatgrass	do	1924		990	1,120	1,080	850	850	978
Slender wheatgrass	do	1924		2,300	560	1,700	690	0	1,050
Bromegrass	do	1924		150	670	2,500	500	600	884

EXPERIMENTS AT REDFIELD, S. DAK.

Only one comparable seeding of these grasses has been made in the United States forage-crop field experiments at Redfield, S. Dak. Under the more favorable moisture conditions bromegrass has given a slightly higher average yield than crested wheatgrass, as shown in Table 14. Slender wheatgrass produced a fair crop of hay the year of seeding, but the yield has not been included in the table. It was more productive than either of the other grasses for the two following years, but had died out completely by the fourth year, while stands of the other grasses remained in good condition. As a result, the average yield of slender wheatgrass was low compared with those of crested wheatgrass and bromegrass.

TABLE 14.—*Average and annual acre yields of air-dry hay of crested wheatgrass, slender wheatgrass, and bromegrass in the United States forage-crop field experiments, Redfield, S. Dak., 1923–1928*

Kind of grass	Method of seeding	Year sown	Acre yield (pounds) of air-dry hay in—						Average
			1923	1924	1925	1926	1927	1928	
Crested wheatgrass	Close drills	1922	2,147	3,299	2,204	308	3,653	1,226	2,140
Slender wheatgrass	do	1922	2,702	4,501	2,385	192	0	0	1,630
Bromegrass	do	1922	1,721	3,680	3,132	192	3,424	1,525	2,279

EXPERIMENTS AT ARDMORE, S. DAK.

The results of a test at the United States Dry Land Field Station, Ardmore, S. Dak., comparing crested wheatgrass and bromegrass sown in close drills, are given in Table 15. High production of both grasses in 1917, 1918, and 1927 was due to favorable moisture conditions during those seasons. In most other years the yields were comparatively low. The average yield of crested wheatgrass for the years 1917 to 1922 was nearly double that of bromegrass. In the 1926 seedings crested wheatgrass again gave a higher average yield than bromegrass.

TABLE 15.—*Annual and average acre yields of air-dry hay of crested wheatgrass and bromegrass at the United States Dry Land Field Station, Ardmore, S. Dak., 1917–1922 and 1927–1930*

Kind of grass	Method of seeding	Year sown	Acre yield (pounds) of air-dry hay in—										Average
			1917	1918	1919	1920	1921	1922	1927	1928	1929	1930	
Crested wheatgrass	Close drills	1916	5,400	4,800	1,100	250	1,400	1,500	.....	.....	.....	.....	2,408
Bromegrass	do	1916	3,400	2,300	240	160	800	800	.....	.....	.....	.....	1,283
Crested wheatgrass	do	1926	.....	.....	.....	.....	.....	.....	2,227	1,533	733	1,135	1,407
Bromegrass	do	1926	.....	.....	.....	.....	.....	.....	2,267	1,100	833	550	1,188

EXPERIMENTS WITH CRESTED WHEATGRASS COMPARED WITH ALFALFA AT VARIOUS STATIONS

That crested wheatgrass will not produce as much hay as alfalfa where soil and moisture conditions are at all favorable is shown by a series of experiments at various stations, the results of which are summarized in Table 16. With one exception, the average yields of alfalfa in experiments at the different stations are greater than those of crested wheatgrass, and the more favorable the moisture conditions the greater is the difference in favor of alfalfa. This fact is demonstrated in the test in the United States forage-crop field experiments at Redfield, S. Dak., where the average yield of alfalfa over a period of six years was more than twice that of crested wheatgrass. Occasionally, owing to rather unusual seasonal conditions, the annual yield of crested wheatgrass is greater than that of alfalfa.

TABLE 16.—*Comparative acre yields of air-dry hay of crested wheatgrass and alfalfa in drilled plots at several experiment stations*

Station and crop	Acre yield (pounds) of air-dry hay in—														Average
	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	
Mandan, N. Dak.:															
Crested wheatgrass[1]								1,922	1,550	730	3,215	2,883	2,000	1,933	2,033
Grimm alfalfa[1]								5,885	3,878	2,516	3,988	[3] 0	2,310	1,788	2,909
Dickinson, N. Dak.:															
Crested wheatgrass					660	2,355	1,581	2,146	1,823	804	2,208	2,427	1,836	1,301	1,714
Grimm alfalfa					170	2,000	3,520	1,960	2,197	506	3,443	2,529	3,339	1,137	2,110
Havre, Mont.:															
Crested wheatgrass					978	1,323	1,140	835	1,120	231	4,143	1,619	1,834	864	1,409
Grimm alfalfa					945	1,290	2,195	1,253	1,290	280	4,287	2,165	1,940	118	1,576
Moccasin, Mont.:															
Crested wheatgrass										2,036	4,629	2,251	1,845	1,049	2,362
Grimm alfalfa										2,244	5,049	4,180	3,245	2,320	3,408
Sheridan, Wyo.:															
Crested wheatgrass								1,000	1,520	3,280	2,680	2,000	2,320	640	1,920
Grimm alfalfa								3,750	3,040	1,320	4,680	2,600	4,880	1,000	3,039
Archer, Wyo.:															
Crested wheatgrass										990	1,120	1,080	850	850	978
Grimm alfalfa										890	670	1,350	1,360	2,500	1,354
Redfield, S. Dak.:															
Crested wheatgrass							2,147	3,299	2,204	308	3,653	1,226	.....	.....	2,140
Grimm alfalfa							3,405	7,653	4,691	1,300	7,892	4,509	.....	.....	4,908
Ardmore, S. Dak.:															
Crested wheatgrass	5,400	4,800	1,100	250	1,400	1,500	.....	.....	.....	.....	.....	.....	.....	.....	2,408
Grimm alfalfa	1,800	5,570	1,170	550	1,600	2,000	.....	.....	.....	.....	.....	.....	.....	.....	2,115
Crested wheatgrass	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2,227	1,533	733	1,135	1,407
Grimm alfalfa	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4,567	1,150	1,160	350	1,807

[1] Average yield of 3 plots in a 6-year rotation.
[2] Yield of a single plot in a variety trial.
[3] No yield because of severe winter injury. Included in average.

Not only is crested wheatgrass unable to compete with alfalfa in amount of hay or pasturage where conditions are favorable, but the feeding value of the alfalfa is also greater. There is considerable danger of bloating, however, when cattle and sheep are pastured on alfalfa, but this trouble is avoided in pasturing crested wheatgrass.

Although crested wheatgrass as a hay crop is generally less productive than alfalfa, it has some advantages as a pasture crop. It furnishes earlier spring and later fall pasturage than most other crops and may be grazed by both cattle and sheep without danger of occasioning bloating, as pasturing on alfalfa sometimes does. It is easier to make a good quality of hay of crested wheatgrass than of alfalfa. Under certain conditions it is easier to obtain a stand of crested wheatgrass than of alfalfa. On abandoned plowed areas the grass maintains a stand in competition with weeds better than either of the other crops. Furthermore, a grass fits into certain rotations better than alfalfa, and crested wheatgrass may be utilized in such cases.

EXPERIMENTS WITH CRESTED WHEATGRASS IN MIXTURES WITH ALFALFA

In some cases crested wheatgrass in mixtures with alfalfa has given a slightly larger tonnage of hay than either crop grown alone under similar conditions. This is particularly true in seasons of favorable moisture, when alfalfa is likely to constitute the bulk of the crop. In dry seasons crested wheatgrass tends to hold the alfalfa in check, and the yield of the combination may or may not equal that of alfalfa grown alone. Where conditions favor a second cutting, this consists almost entirely of alfalfa. The rate of seeding suggested for the mixture is 3 to 4 pounds of crested-wheatgrass seed per acre and a little less than the usual quantity of alfalfa seed when sown alone.

The results obtained from a combination of crested wheatgrass and alfalfa at the field station at Mandan, N. Dak., are shown in Table 17. Field A is not so favorably located as field B, which is on lower land along a small coulee where moisture conditions are more suitable for hay production. Field C, constituting the most favorable portion of field B, gave the highest yields of hay. The first cutting of the mixture usually yields more than alfalfa alone, and mixed seeding would seem to be advisable where only one cutting of alfalfa is normally obtained. The second cutting contains very little crested wheatgrass.

TABLE 17.—*Acre yields of air-dry hay of crested wheatgrass and alfalfa grown as a mixture in close-drilled plots, in different locations at the United States Northern Great Plains Field Station, Mandan, N. Dak., 1921–1930*

Year	Acre yield (pounds) of air-dry hay in—			Year	Acre yield (pounds) of air-dry hay in—		
	Field A [1]	Field B [2]	Field C [3]		Field A [1]	Field B [2]	Field C [3]
1921	.....	3,140	.....	1927	2,291	5,060	5,960
1922	.....	4,122	.....	1928	2,111	4,652	8,500
1923	.....	4,841	.....	1929	1,793	3,170	4,680
1924	3,518	5,698	4,860	1930	1,345	2,942	5,000
1925	2,359	4,651	6,920				
1926	405	2,113	4,348	Average	1,975	4,039	5,753

[1] Field of 2.8 acres located on higher ground with less favorable moisture conditions.
[2] Field of 4.5 acres located along coulee with favorable moisture conditions.
[3] Portion (0.25 acre) of field B especially favorably located as regards moisture conditions.

A mixture of crested wheatgrass and Grimm alfalfa was sown at the Dickinson substation in the spring of 1927 on land where Grimm alfalfa had winterkilled following the drought of 1926. In this mixed seeding, crested wheatgrass was not conspicuous until the dry spring of 1930, the third year after seeding, when it started growth earlier than the alfalfa and made up most of the hay, except in low places, where the alfalfa was more vigorous. After the crop was harvested, about June 20, the alfalfa made a more rapid recovery and with sufficient moisture would have made a good crop. After the September rains the crested wheatgrass made considerably more growth than the alfalfa.

RELATION OF AGE OF STAND TO PRODUCTIVITY

During the progress of the experiments with crested wheatgrass, slender wheatgrass, and bromegrass it was apparent that the productivity varied with the age of the stand and that some of the grasses

FIGURE 9.—A double row of crested wheatgrass along the main road at the United States Northern Great Plains Field Station, Mandan, N. Dak., showing early spring growth of fully 8 inches. A drilled plot of bromegrass is shown at the right. Photographed May 15, 1924

continued to produce satisfactorily for more years than others. This relationship is brought out to a certain extent in Table 18, which has been compiled by averaging yields obtained from stands 1, 2, 3, and 4 years old, respectively. These data indicate that the yields the first year after seeding are likely to be moderate, owing to the fact that the grasses have not become thoroughly established. With favorable moisture conditions the maximum yields of all these grasses may be expected during the second and third years. After the third year yields tend to decline, though crested wheatgrass has a longer productive life than bromegrass or slender wheatgrass. Bromegrass tends to become sod bound in a few years, thus reducing yields, but stands of slender wheatgrass seldom remain in a satisfactory condition more than three or four years. To a large extent yields are de-

termined by the seasonal moisture conditions, and the production fluctuates with the moisture supply regardless of the age of the plots so long as the stand remains satisfactory. It appears, however, that the older stands require more moisture than new stands, probably owing to the fact that there has been considerable thickening of the stands and that there may be a shortage of subsoil moisture.

TABLE 18.—*Average acre yields of air-dry hay of crested wheatgrass, slender wheatgrass, and bromegrass one to four years after seeding at places named*

Station and grass	Method of seeding	Acre yield (pounds) of air-dry hay in—			
		First year	Second year	Third year	Fourth year
Mandan, N. Dak.:					
Crested wheatgrass (south field)	Close drills	2,586	2,475	2,463	[1] 1,609
Crested wheatgrass (main field)	do	[2] 2,090	973	1,238	[1] 871
Moccasin, Mont.:					
Crested wheatgrass	do	2,599	2,733	1,659	1,542
Do	Rows	1,980	3,472	2,156	[3] 1,731
Slender wheatgrass	Close drills	2,907	1,144	1,851	[3] 1,002
Bromegrass	do	2,538	3,059	1,399	1,528
Havre, Mont.:					
Crested wheatgrass	Rows	1,285	2,473	2,408	1,662
Do	Close drills	1,336	1,661	2,659	1,206
Slender wheatgrass	Rows	1,768	2,753	2,956	1,200
Do	Close drills	1,302	2,392	2,666	970
Bromegrass	Rows	1,118	2,123	2,410	982
Do	Close drills	1,208	1,708	1,770	875
Sheridan, Wyo.:					
Crested wheatgrass	Rows	1,200	1,587	1,760	1,727
Do	Close drills	2,347	2,587	2,347	1,610
Bromegrass	Rows	2,560	2,540	2,667	2,053
Do	Close drills	1,760	1,440	980	460

[1] These plots were cut early in June and plowed before normal harvesting date.
[2] Contained some volunteer sweetclover.
[3] Yields from one seeding.

FOR PASTURE

The nature of crested wheatgrass makes it a most valuable addition to the few grasses available for cultivated pastures in the northern Great Plains. Through its ability to start growth early in the spring (fig. 9) and to grow late in the fall, it fills a pasture need that is not met by other plants that are available for cultivated pastures in this area. In normal seasons the grass becomes practically dormant during hot, dry summer periods, growth being renewed again in the fall provided moisture conditions are favorable. As a result of the ability of the grass to grow at low temperatures, it furnishes pasturage earlier in the spring and later in the fall than other cultivated grasses. As crested wheatgrass tends to become more or less dormant during hot weather, it should be used in combination with some other cultivated or native pasture that supplies grazing during the summer months; by so doing the grazing period can be prolonged several days. In the locality of Mandan, N. Dak., crested wheatgrass is ready to graze the latter part of April, and it should be grazed rather heavily during May and the first part of June. The stock should then be transferred to a sweetclover or native pasture. If the season is favorable the crested wheatgrass may again be grazed in the fall.

In tests conducted at the field station at Ardmore, S. Dak. (*1*), crested-wheatgrass pasture was compared with bromegrass pasture, native pasture, and sweetclover pasture. This test showed that

crested wheatgrass pastured by dairy cows for four years, 1922 to 1925, averaged $7.70 per acre per year in value, bromegrass averaged $6.75 per acre, sweetclover $6.63 per acre, and native pasture $4.43 per acre. These pastures were continued through 1930 without reseeding the bromegrass or the crested wheatgrass, but it was necessary to reseed the sweetclover several times.

Crested wheatgrass for pasture has been tried at the field station at Mandan, N. Dak., in only a small way. Observations were made on a field of 4 acres included in the cow pasture. The grass is the first to start in the spring, and early grazing is mostly on this grass. Observations for 10 years at this station show that crested wheatgrass starts growth about April 1 and bromegrass about April 7. In some years the difference amounts to only 4 or 5 days, and in other years to 10 days to 2 weeks. Slender wheatgrass starts at approximately the same time as bromegrass. These grasses are usually in condition for pasturing about three weeks after the growth starts.

In discussing seed mixtures for irrigated pastures in Colorado, Hanson (*7, p. 45*) says:

> Crested wheatgrass is a long-lived perennial bunch grass that has just recently been placed on the market. The merits of this grass are its great drought resistance, winter hardiness, early growth, nutritiousness, and palatability. It begins growth and develops herbage for grazing earlier, it appears, than any other tame species, and even earlier than most native species. It is adapted particularly for pastures on which little or no irrigation water is available.

EXPERIMENT AT MOCCASIN, MONT.

In 1926 a pasture experiment (*11*) with dairy cows was begun at the Judith Basin Branch Station, Moccasin, Mont., comparing bromegrass, crested wheatgrass, and sweetclover. The four years' results show bromegrass to have a slight advantage over both crested wheatgrass and sweetclover with respect to length of pasture season and carrying capacity. It required 1.50 acres of bromegrass for one animal for 68 days as compared with 1.58 acres for 67 days for crested wheatgrass and 1.52 acres for 65 days for sweetclover. Placing this on the basis of a 6-month grazing period, 4.0 acres of bromegrass, 4.3 acres of crested wheatgrass, or 4.3 acres of sweetclover would be required to carry an animal. These averages are considerably less than the acreage of native grass required to carry an animal a similar period. Although bromegrass and crested wheatgrass have given practically equal returns from pasturing, the latter as a rule is ready for grazing about 10 days earlier in the spring, and the fall growth is more abundant. Bromegrass has shown a tendency to stand up better during the summer or drier season of the year.

CLIPPING EXPERIMENTS AT DICKINSON, N. DAK.

In 1928 a clipping test was made at the Dickinson Substation to determine the relative amounts of growth of crested wheatgrass, bromegrass, slender wheatgrass, and native growth consisting of approximately 90 per cent of blue grama (*Bouteloua gracilis* Lag.), 5 per cent of western wheatgrass (*Agropyron smithii*), and 5 per cent of other grasses and weeds, when clipped frequently to approximate yields under grazing conditions. The results are shown in Table 19.

TABLE 19.—*Actual and relative air-dry yields of crested wheatgrass, slender wheatgrass, bromegrass, and native grasses grown in close-drilled plots and cut at 15-day intervals from April 10 to July 25, 1928, at the Dickinson Substation, Dickinson, N. Dak.*

Date	Actual progressive yield				Relative progressive yield (crested wheatgrass=100)		
	Crested wheatgrass	Slender wheatgrass	Bromegrass	Native grasses	Slender wheatgrass	Bromegrass	Native grasses
	Grams	*Grams*	*Grams*	*Grams*	*Per cent*	*Per cent*	*Per cent*
Apr. 10	98	16	(1)		16		
Apr. 25	163	38	48		23	29	
May 10	340	102	157	48	30	46	14
May 25	478	182	311		38	65	
June 10	[1] 478	218	[1] 311		46	65	
June 25	540	269	425	243	50	79	45
July 10	672	389	541		58	81	
July 25	745	461	637	557	62	86	75
Aug. 10	745			579			77

[1] Growth was not sufficient to cut; total if given is the same as on the previous date.

These data show that crested wheatgrass started growth earlier than the other grasses and that it was more productive during the period covered by these clippings.

FOR IMPROVEMENT OF RANGE AND RESEEDING ABANDONED PLOWED AREAS

Crested wheatgrass has been used in a number of places with good results in reseeding depleted range and abandoned plowed areas where a grass cover is desired instead of the weeds that usually come in on such lands. The United States Forest Service (*4*) has used crested wheatgrass with good results in reseeding range land at certain elevations in northern areas. In Canada the Dominion Range Experiment Station, Manyberries, Alberta, reported (*10*) that among several species of grasses and clovers used for reseeding abandoned plowed farm land crested wheatgrass appeared most promising. In eastern Oregon crested wheatgrass is reported[7] to be giving better results than other grasses used for reseeding depleted range lands. In Colorado crested wheatgrass gave good results in mixtures for early spring and fall pasture (*6*) on range land at high elevations and was successful when used for reseeding abandoned plowed areas (*5*). At Sandpoint, Idaho, when used for seeding burned-over timberland, it was not considered promising under conditions where timothy, orchard grass, bromegrass, and meadow fescue do well.[7]

FOR LAWNS

Crested wheatgrass can be used on the lawn where water is not available to maintain the more desirable lawn grasses. When used for this purpose the rate of seeding should be increased to 20 to 30 pounds per acre if sown with a grain drill or 40 to 50 pounds when sown broadcast. It withstands drought for longer periods than the common lawn grasses. Its deep-green color in the spring before other grasses start is very pleasing, but it has the undesirable characteristic of becoming brown during prolonged hot periods. In the fall when the weather becomes cool growth is resumed.

[7] Unpublished correspondence.

SEED PRODUCTION

Crested wheatgrass has much better seed habits than the other perennial grasses, such as slender wheatgrass and bromegrass, commonly cultivated in the northern Great Plains. It should be cut for seed when about one-half the heads have turned brown or soon after the earliest heads begin to shatter, which is usually between July 15 and August 1. The seed shatters so readily that much of it may be lost in harvesting if allowed to become too mature, especially if strong winds occur at this time. It may be harvested with a grain binder, and to avoid shattering in dry weather it is best to cut only during the forenoon while the grass contains considerable moisture.

The seed is easily threshed with an ordinary grain separator, though it is necessary to reduce the current of air from the fan or blower to avoid the loss of good seed. As the seed comes from the thresher it

FIGURE 10.—Double row of crested wheatgrass along a road at the United States Northern Great Plains Field Station, Mandan, N. Dak., just before harvesting for seed. Sown in the spring of 1921, the row yielded at the average rate of 15 pounds of clean seed per 8 rods of row in 1924, the year in which it was photographed

usually contains many broken stems, and it should be run through a fanning mill to remove these. If the rear of the machine is set 5 to 6 inches lower than the front, ordinarily the separator handles the straw more successfully and the seed passes back to the delivery spout more freely.

At the various experiment stations where crested wheatgrass has been harvested for seed the yields have ranged from a total failure in dry seasons to 600 to 800 pounds per acre in favorable seasons. The best yields are usually obtained following a wet spring. A good average yield would probably be about 250 to 300 pounds per acre. Double rows have yielded better than single rows, which in turn have generally produced better crops than close-drilled plots. Crested wheatgrass generally has produced more seed per acre than the other grasses.

As is shown in Table 20, yields of crested-wheatgrass seed at the northern Montana branch station, Havre, Mont., have varied from

nothing to 630 pounds per acre. The comparative data are limited, but it appears that this grass may be expected to produce more seed per acre than bromegrass or slender wheatgrass. Rows have generally yielded more than close-drilled seedings.

TABLE 20.—*Annual and average acre yields of seed of crested wheatgrass, slender wheatgrass, and bromegrass at stated places*

Station and grass	Method of seeding	Acre yield (pounds) in—										Average
		1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	
Havre, Mont.:												
Crested wheatgrass	Rows	630	350	(1)	105	191	38	450	143	360	0	252
	Close drills				163	165	17	(1)	138	210	0	116
Slender wheatgrass	Rows								263	130	0	131
	Close drills								228	80	0	103
Bromegrass	Rows								335	200	0	178
	Close drills								248	80	0	109
Mandan, N. Dak.: [2]												
Crested wheatgrass	Double rows [3]					(4)	432	376	31	175	128	228
	do				796	420	302	475	54	163	124	333
	do [5]				360	110	141	172	31	78	47	134
	Single rows [5]			116	392	67	104	170	14	95	95	132
	do [3]					123	134	314	59	300	209	190
	Close drills [5]					342	90	210	0	31	33	118
Dickinson, N. Dak.:												
Crested wheatgrass	Rows	151	348	252	590	(6)	100	211				275
	do							198	182	254	256	223
	do										286	286
	Close drills	233	459	217	433		100	133				263
	do							235	135	238	69	169
	do										304	304
Slender wheatgrass	Rows	125	308	49	240		0	0				120
	do							323	249	211	0	196
	do										177	177
	Close drills	160	661	173	590		0	0				264
	do							683	414	126	0	306
	do										59	59
Bromegrass	Rows	143	314	163	440		0	171				205
	do							126	182	218	142	167
	do										210	210
	Close drills	180	265	174	408		0	125				192
	do							173	87	148	0	102
	do										255	255

[1] No data available.
[2] The first seed crop at Mandan was harvested in 1917 from the 1915 seeding and yielded at the rate of 340 pounds per acre.
[3] Favorable locations.
[4] Good crop of seed harvested but identity lost.
[5] Generally unfavorable locations.
[6] Seed not threshed in 1925.

Crested-wheatgrass seed has been produced at the field station at Mandan, N. Dak., for a number of years, with variations in yield due to the fact that some of the plots are more favorably located than others. In favorable seasons a yield of 300 to 500 pounds of seed per acre is not unusual. A good crop seems to depend largely on abundant spring rains. A double row of crested wheatgrass sown along the roadway and very favorably located as regards moisture, since there was a 4-foot cultivated area on one side and a 30-foot roadway on the other, yielded at the average rate of 15 pounds of clean seed per 8 rods of row in 1924. If it is assumed that this row utilized a strip of land approximately 7 feet wide, the yield was at the rate of 750 pounds per acre. (Fig. 10.) During the period from 1918 to 1930, inclusive, this station distributed nearly 2,700 pounds of seed. Of this quantity, 1,200 pounds went directly to farmers, 500 pounds to farmers through county extension agents, 500 pounds to experiment stations in the United States and Canada, and 500 pounds to the

Division of Forage Crops and Diseases, United States Department of Agriculture, for distribution.

Yields of crested-wheatgrass seed at the Dickinson Substation, Dickinson, N. Dak., ranged from a total failure in an old stand in a dry year to a maximum of 590 pounds per acre in 1924. The average yield in rows was about 250 pounds per acre. The best yields of both hay and seed were produced following a wet spring. For instance, in 1927, when the May rainfall amounted to 5.67 inches, a close-drilled plot yielded 559 pounds of clean seed and 2½ tons of hay per acre. The following year, when the May rainfall was 1.22 inches, the same field yielded only 50 pounds of seed per acre.

As shown in Table 20, crested wheatgrass in rows gave somewhat higher average yields of seed than slender wheatgrass or bromegrass. In close drills crested wheatgrass gave higher average yields of seed than bromegrass but generally somewhat less than slender wheatgrass. The low yield of slender wheatgrass in the 1929 seeding was due to dry weather at a critical time.

During the period 1922 to 1930, more than 10,000 pounds of crested wheatgrass seed was distributed by the Dickinson substation. This was sent into 13 States and into 4 Provinces of Canada.

VIABILITY OF SEED

The seed of crested wheatgrass retains its viability remarkably well. In 1926, 18 selections of this grass were made at the field station at Mandan, N. Dak. In the spring of 1930 seed of each of the lots was planted in pots in the greenhouse, and the germination was high. In the fall of 1930 numerous lots of crested-wheatgrass seed were obtained from various sources by Love [8] for the purpose of making germination tests. The lots of seed varied in age from 11 years (seed produced in 1919) to less than 1 year (grown in 1930).

Among the lots of seed tested were 14 from 28 original selections made at Mandan in 1920. The germination of the 10-year-old seed of two of these selections was 20 and 30 per cent, respectively, while the others varied from 0 to 8 per cent. Seeds of the same 14 selections, produced in 1923, showed a germination ranging from 10 to 62 per cent. The same two selections previously highest in germination were again high, with percentages of 50 and 62. Seed produced in 1926 was available from all of the 28 selections. The tests showed that 9 of these germinated 90 to 95 per cent, 16 selections 80 to 89 per cent, 2 selections 74 and 79 per cent, and the lowest germinated 62 per cent.

These tests show that crested wheatgrass seed retains its viability for several years and that certain strains retain their viability better than others. Any grass that will retain its viability for four or five years should meet the requirements for commercial and farm use.

DISEASES

One of the outstanding characteristics of crested wheatgrass seems to be its freedom from disease. In the United States stem rust has been reported as occurring on the grass, and notes on some of the selections obtained from Russia indicate that in that country the

[8] LOVE, L. D. LIFE HISTORY AND HABITS OF CRESTED WHEATGRASS. (Thesis presented for the degree of master of science at the N. Dak. Agr. College.) 1931.

grass is sometimes attacked by the stem rust. The disease has not been observed on this grass at Mandan or Dickinson, N. Dak., although it has sometimes affected slender wheatgrass rather seriously. The grass also seems to be remarkably free from ergot, but occasionally a light infection occurs. Most of the ergot is removed from the seed in cleaning, and if the crop is to be used for hay it should be cut before the ergot has had time to develop. In the case of slender wheatgrass and western wheatgrass, ergot is sometimes serious. Occasionally it is so abundant that when the hay is fed to cattle they are seriously affected.

WEED CONTROL

After crested wheatgrass is once established it usually dominates most weeds. Among the weeds that it has been found to control to a large extent are wild oats, wild rose, and French weed or fanweed. In the drier locations it tends to decline in vigor after six to eight years, and some of the more persistent weeds may invade the field.

SUMMARY

Crested wheatgrass (*Agropyron cristatum*), a native of the cold, dry plains of Russia and Siberia, was introduced into the United States through the effort of the United States Department of Agriculture in 1898. As far as known, however, none of the grass now growing in this country traces back any farther than to an importation made in 1906 under S. P. I. No. 19536.

Crested wheatgrass is a perennial bunch grass closely related to slender wheatgrass (*Agropyron tenerum*) and western wheatgrass (*A. smithii*).

It is characterized by its long productive life, its ability to grow at lower temperatures than other grasses adapted to the same general condition, and its tendency to become dormant during hot dry periods. As a result of its ability to grow at low temperatures, it starts growth earlier in the spring and continues to grow later in the fall than other grasses.

There is a wide variation in the individual plants from commercial lots of seed as regards leafiness, hairiness, fineness, type of head, and length of awns.

A fair standard for the seed is a bushel weight of 22 pounds, purity of 88 to 90 per cent, and germination 90 per cent.

Crested wheatgrass seems especially well adapted to the northern Great Plains, where the temperatures are severe and the moisture supply limited. It does well on productive soils of almost any texture.

A firm, fine seed bed well supplied with moisture is essential to a satisfactory stand of the grass.

The most favorable time for seeding varies with the season and local conditions, but the usual practice is to sow about the time of sowing spring wheat.

Crested wheatgrass may be sown in close drills or in rows far enough apart to permit cultivation. Where the crop is to be utilized for hay or pasture the close drills are preferable except where the moisture supply is very limited. The seed may be sown with an ordinary grain drill, care being taken to avoid covering too deeply.

In general more satisfactory stands and somewhat higher subsequent yields are obtained from seedings made without a nurse crop than with one.

Close-drilled seedings should be made at the rate of 10 to 12 pounds per acre. Seeding rates of 2 to 3 pounds per acre are ample for single rows and 4 to 5 pounds for double rows 42 inches apart.

Ordinarily a close-drilled field of crested wheatgrass does not require any attention the year it is sown. Row seedings require cultivation to keep down the weeds.

The average of several analyses of crested wheatgrass made at various stages of growth show a somewhat higher protein content than that of bromegrass or slender wheatgrass. Crested wheatgrass grown in rows contains more protein than that grown in close drills.

So far as palatability and quality are concerned, crested wheatgrass compares most favorably with other grasses utilized for the production of hay in the northern Great Plains.

In comparative tests extending over a period of about 15 years crested wheatgrass has generally yielded somewhat better than bromegrass or slender wheatgrass. Both bromegrass and slender wheatgrass frequently yield more the first two or three years, after which the slender wheatgrass tends to die out and the bromegrass becomes sod bound, while the crested wheatgrass continues to produce satisfactorily, provided moisture conditions are favorable.

Owing to the ability of crested wheatgrass to grow at lower temperatures than other cultivated grasses, it furnishes pasturage earlier in the spring and later in the fall. In carrying capacity it is at least equal to other grasses generally grown in the northern Great Plains. As it tends to become more or less dormant during the hot dry weather, it should be used in combination with some other cultivated or native pasture which supplies grazing during the summer months, thereby prolonging the grazing period.

Crested wheatgrass has excellent seed habits. It should be harvested for seed when about one-half the heads have turned brown. Yields of seed have varied all the way from nothing in dry years to more than 700 pounds per acre in favorable seasons. A good average yield is 250 pounds per acre.

Crested wheatgrass does not yield so much hay as alfalfa where moisture conditions are favorable to the latter, but it frequently yields more where the moisture supply is limited. In some cases it can be sown in mixture with alfalfa to advantage, the yield of the mixture frequently exceeding that of either crop grown alone.

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BIOLOGY AND CONTROL OF THE CORN LEAF APHID WITH SPECIAL REFERENCE TO THE SOUTHWESTERN STATES

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CONTENTS

	Page		Page
Introduction	1	Sexual forms	13
History of the corn leaf aphid in the United States	2	Males	14
Distribution	2	Description of male *Aphis maidis*	15
Food plants	5	Natural checks	16
Field history	7	Adverse weather conditions	16
Type and extent of injury	7	Insect and other enemies	17
Life history	8	Control	19
Cages used in life-history studies	9	Time of planting	19
Difficulties encountered	9	Pasturing	19
Generation experiments	9	Spraying and dusting	19
Length of instars	12	Summary	19
Viviparous forms	12	Literature cited	20

INTRODUCTION

The corn leaf aphid (*Aphis maidis* Fitch) has been observed by many entomological workers on numerous different cultivated plants in various sections of the United States over a period of nearly 75 years. Many articles have been published regarding this insect, but, with the exception of Forbes, who shows the difference between the corn leaf aphid and the corn root aphid (*Aphis*) *Anuraphis maidiradicis* Forbes (*11*, *12*, *13*),[2] no one has attempted to give a complete detailed account of the biology of the species.

This bulletin describes a study begun in 1910 by the senior writer at El Centro, Calif. During that year many field observations were made on *Aphis maidis* as a serious pest of barley. Fields of barley were discovered to be intensely infested with this aphid, and serious injury was noted. Subsequent studies revealed the fact that it was the most serious insect pest of barley in the southwestern part of the United States. In the following year at Tempe, Ariz., life-history studies of this species were begun and have been continued with the assistance of other members of the Tempe laboratory and the junior

[1] The authors wish to express their appreciation of the many courtesies shown them by Joe S. Wade, of the Bureau of Entomology, and of his valuable assistance with the literature of this species. They are especially grateful for access to his bibliography of the species.

[2] Italic numbers in parentheses refer to Literature Cited, p. 20.

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author to the present date. Other workers in the Bureau of Entomology also have made many observations and studies of the species at other points in the United States. The work of R. A. Vickery at Brownsville, Tex., has been particularly helpful.

Our knowledge of the life history of this insect is incomplete in several respects. Even after a continuous study of this species covering a period of 20 years, an oviparous female has never been obtained or observed. Nor has the development of every instar of the male been carefully noted. Males were obtained by rearing only in rare cases and never in the field.

HISTORY OF THE CORN LEAF APHID IN THE UNITED STATES

Although this insect was probably well known previous to 1856, the first recorded observation seems to be that of Fitch (*10, p. 318*), who states:

> In August, the person who is selecting soft corn for boiling will sometimes come to an ear, the stem of which is entirely covered with vermin. * * * They occur upon no other part of the stalk except the peduncle or stem which bears the ears.

He recognized this as a new species plainly differing "from one which infests the maize in Europe, the *Aphis zeae*, of Bonafous," and proposed to call it the maize aphid (*Aphis maidis*).

About the end of May, 1861, the attention of Walsh was called to an aphid attacking the roots of corn near Rock Island, Ill. He compared specimens of this with the aphid described by Fitch and states (*21, p. 492*):

> As his description agrees tolerably well with that of the species which I found attacking the roots of corn in June, and as, in particular, he describes the antennae as being not quite half as long as the body, I suspect that they are the same insect, and that its normal habitat is the roots of the corn plant, but that later in the season when these dry up it betakes itself, to avoid starvation, to the stem of the ear.

Thomas (*18*) apparently accepted this determination and reports it as being found on the tassels, ear stalks, and roots of Indian corn.

S. A. Forbes and his assistants began observations on this insect in 1882. For a time they also apparently accepted the theory that the two forms represented the same species, but later they began to have some doubt. In 1891 Forbes (*11*) definitely determined the two forms as distinct species and proposed the name *Aphis maidiradicis* for the root form. Three years later (*12*) he again called attention to this difference and the inability of his assistants, H. Garman, C. M. Weed, and John Martin, to breed one form from the other. He also pointed out a difference in preference of host plants and gave the characters which differentiate the two species.

DISTRIBUTION

Aphis maidis is found throughout the greater part of the world between the latitudes of 40° N. and 40° S. (Fig. 1.) In North America its northern limit is somewhat farther north and coincides fairly well with the latitude of the northern border of the United States. Records in the files of the Bureau of Entomology indicate that it occurs in every State in the Union with the possible excep-

FIGURE 1.—Distribution of *Aphis maidis* Fitch throughout the world

tion of Montana, Idaho, Wyoming, Utah, and Nevada. It may occur even in these States, but no records of such distribution have been found. (Fig. 2.)

The species is apparently of little importance in Canada. Glendenning does not include it in his List of the Aphididae of British Columbia and the supplement thereto. The only records found in literature of its occurrence elsewhere in Canada were from Nova Scotia, Ontario, and Quebec. Spittal (*17*) states that moderate infestations were found at Weymouth, Digby County; Wilmot, Annapolis County; and Berwick, Kings County, Nova Scotia. Caesar and Ross (*5*, *p. 24*) record its presence in Ontario in the following words:

> Dark green aphids were very numerous in most corn fields during August and September. They fed on the new growth in August, and in September were chiefly in the sheltered areas between the stem and the enveloping leaves.

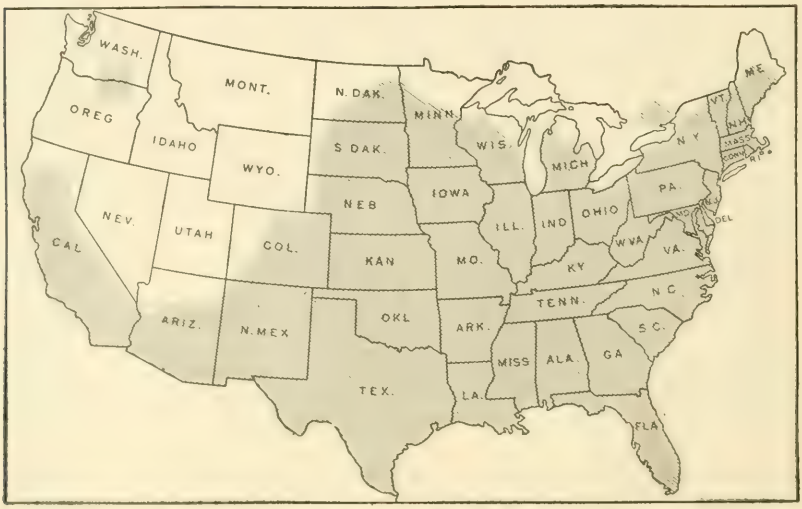

FIGURE 2.—Distribution of *Aphis maidis* in the United States

G. H. Hammond, of the Dominion entomological laboratory at Hemmingford, Quebec, in a letter to the junior author states that he found the species common in a single field of corn at Hemmingford, Quebec, on September 14, 1929. A single specimen was found in the collection of the United States National Museum labeled Montreal.

The records from Mexico are likewise very meager. A single reference was found in the records of the United States insect pest survey and one in literature (*16*), each recording its presence in Mexico but giving no locality. The authors have observed the insect as a serious pest in the United States near the Mexican border from Brownsville, Tex., to San Diego, Calif. A. L. Herrera, formerly in charge of the direction of biological studies in Mexico, in a letter to the authors says, "*Aphis maidis* is a pest in Mexico, in the corn and other plants," and Alfonso Dampf, of the Federal office for the defense of agriculture of Mexico, writes that he has seen the species on sugarcane.

In Europe corn is frequently attacked by *Aphis zeae* Bon., which closely resembles *A. maidis* Fitch, but which is considered a quite distinct species. Del Guercio (*9*) mentions *A. maidis* as new to Italy, but states that he considers the Italian form a variety of *A. maidis* of America and points out that some differences are observed. No other writer has reported its occurrence in Europe. Since this aphid has been shown to be the only known agent in the dissemination of sugarcane mosaic (*6*), it seems possible that it may be present in southern Spain, where this disease was recently found. This species was found in Java and described under the name *Aphis adusta* Zehntner, which appears to be the only synonym.

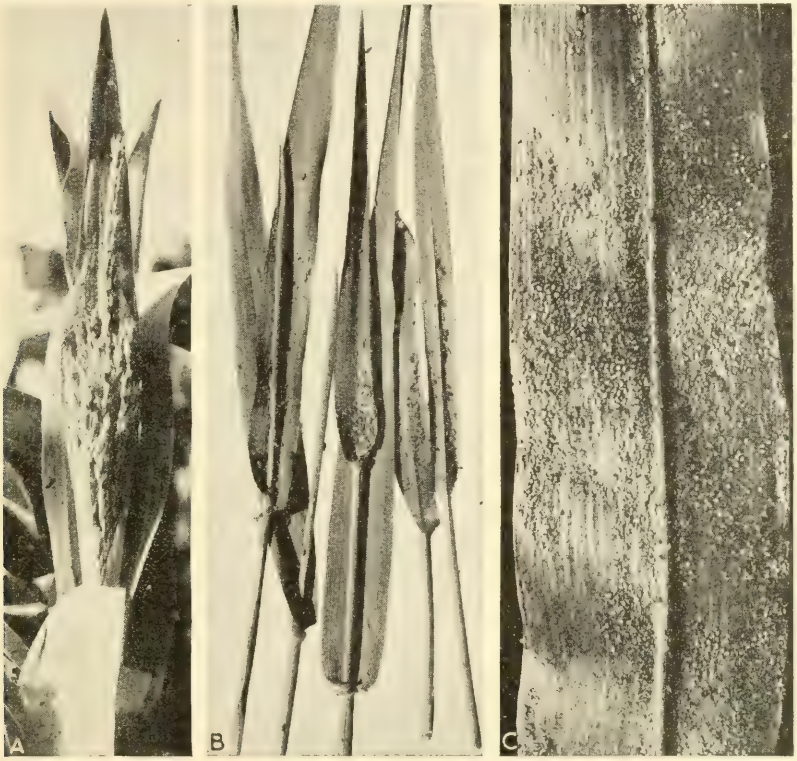

FIGURE 3.—Plants heavily infested with corn leaf aphids: A, Corn; B, barley; C, parasitized aphids on sorghum

FOOD PLANTS

The recorded food plants of the corn leaf aphid include a great number of the common wild and cultivated grasslike plants and also a few common weeds. In the United States barley, grain sorghums, and corn are possibly the favored food plants, with preference shown in the order named. (Fig. 3.) In the sugarcane-growing regions this insect has attracted considerable attention in late years, as it has been shown to transmit a serious disease of sugarcane known as mosaic. Apparently *Aphis maidis* does not normally feed on the

cane to any great extent, but does this only incidentally or when forced to do so by the destruction of its normal food in the cultivation of the fields. Several investigators, working in foreign countries, have had difficulty in keeping this insect alive on sugarcane. Brandes, however, reports its occasional presence on the sugarcane in large numbers (*1*). It is questionable whether this aphid breeds normally on any host other than species of the botanical group Gramineae. Most records of occurrence on hosts belonging in other groups may be due either to mistaken identity or to the casual resting of migrant forms, although Davis (*8*) records it as feeding normally in his cages on *Polygonum pennsylvanicum* L.

The accompanying list of host plants (Table 1) has been compiled from observations by the authors and from notes made by several other members of the Bureau of Entomology, together with a few records, chiefly foreign, from the literature. Many of the foreign hosts listed also occur in the United States, but they did not come under the observation of the authors.

TABLE 1.—*Host plants of the corn leaf aphid*

Scientific name of plant	Common name of plant	Locality	Relative abundance
Ambrosia trifida L.	Great ragweed	United States	Unknown.
Arundo donax L.	Carrizo, giant reed	Peru	Common.
Avena sativa L.	Oat	United States	Rare.
Axonopus scoparius (Flügge) Kuhlm.	Gramalote	Peru	Common.
Cenchrus echinatus L.	Sand bur	Cuba	Rare.
Cynodon dactylon (L.) Pers.	Bermuda grass	do	Occasional.
Cyperus esculentus L.	Chufa	United States	Rare.
Dactyloctenium aegyptium (L.) Richt.	Crowfoot grass	Cuba	Occasional.
Digitaria chinensis (Nees) A. Camus		Unknown	Rare.
Digitaria debilis (Desf.) Willd.		do	Do.
Digitaria horizontalis Willd.		Porto Rico	Common.
Digitaria pruriens (Trin.) Buese.		Unknown	Rare.
Digitaria sanguinalis (L.) Scop.	Crabgrass	United States	Common.
Echinochloa colonum (L.) Link	Jungle rice	Cuba	Preferred host.
Echinochloa crusgalli (L.) Beauv.	Barnyard grass	do	Occasional.
Elusine indica (L.) Gaertn.	Goose grass	United States	Do.
Eragrostis pilosa (L.) Beauv.		Chosen	Unknown.
Eriochloa polystachya H. B. K.	Malojillo	Cuba	Common.
Eriochloa punctata (L.) Desv.		United States	Rare.
Hordeum murinum L.		do	Do.
Hordeum vulgare L.	Barley	do	Preferred host.
Leptochloa virgata (L.) Beauv.		Cuba	Occasional.
Miscanthus sinensis Anderss.	Eulalia	do	Rare.
Muhlenbergia mexicana (L.) Trin.		United States	Occasional.
Oxalis sp.		do	Unknown.
Panicum barbinode Trin.	Para grass	Cuba	Rare.
Panicum capillare L.	Witch grass	United States	Unknown.
Panicum dichotomiflorum Michx.		do	Rare.
Panicum hemitomon Schult.	Maiden cane	do	Common.
Panicum miliaceum L.	Broomcorn millet	do	Unknown.
Panicum sp. (probably *Paspalum distichum L.*)	Ditch grass	do	Occasional.
Paspalum boscianum Flügge	Bull grass	do	Do.
Paspalum conjugatum Berg.		Porto Rico	Rare.
Paspalum fimbriatum H. B. K.		Cuba	Do.
Paspalum virgatum L.		do	Do.
Pennisetum glaucum (L.) R. Br.	Pearl millet	do	Occasional.
Phragmites communis Trin.	Reed	United States	Do.
Plantago major L.	Plantain	do	Unknown.
Poa pratensis L.	Kentucky bluegrass	do	Occasional.
Polygonum pennsylvanicum L.	Lady's-thumb	do	Unknown.
Rottboellia exaltata L. F.	Rice grass	Jamaica	Common.
Rottboellia glandulosa Trin.		Sumatra	Occasional.
Rumex altissimus Wood	Pale dock	United States	Unknown.
Saccharum narenga (Nees) Hack.	Wild sugarcane	Cuba	Occasional.
Saccharum officinarum L.	Sugarcane	United States	Rare.
Scirpus maritimus L.	Bulrush	Hawaii	Unknown.
Secale cereale L.	Rye	United States	Rare.
Setaria aurea Hochst.	Ratttail grass	Australia	Common.
Setaria italica (L.) Beauv.	Millet	United States	Do.
Setaria lutescens (Weigel) Hubb.	Yellow foxtail	do	Occasional.
Setaria viridis (L.) Beauv.	Green foxtail	do	Do.

TABLE 1.—*Host plants of the corn leaf aphid*—Continued

Scientific name of plant	Common name of plant	Locality	Relative abundance
Selanum rostratum Dunal	Buffalo bur	United States	Rare.
Sorghum dora Griseb	Sorghum	do	Unknown.
Sorghum halepense (L.) Pers	Johnson grass	do	Occasional.
Sorghum vulgare Pers. (form)	Wonder forage grass (?).	Cuba	Do.
Sorghum vulgare Pers	Sorghum	United States	Preferred host.
Sorghum vulgare var. *caffrorum* (Beauv.)	Kafir	do	Do.
Sorghum vulgare effusum (Hack.)		Peru	Unknown.
Sorghum vulgare var. *exiguum* (Forsk.)	Tunis grass (?)	Cuba	Occasional.
Sorghum vulgare var. *saccharatum* (L.) Boerl	Sorgo	United States	Unknown.
Sorghum vulgare var. *sudanense* (Piper) Hitchc	Sudan grass	do	Occasional.
Sorghum vulgare var. *technicum* (Koern.)	Broomcorn (?)	do	Preferred host.
Sporobolus virginicus (L.) Kunth		Porto Rico	Rare.
Triticum aestivum L	Wheat	United States	Do.
Tripsacum laxum Nash	Guatemala grass	Hawaii	Common.
Typha latifolia L	Cattail	United States	Unknown.
Zea mays L	Corn	do	Preferred host.

FIELD HISTORY

During the summers in the South and Southwest the corn leaf aphid is held in check both by the extreme heat and by its natural enemies. When cool weather appears, it reproduces rapidly on the late corn and sorghums until these either mature or are killed by frosts, and then migrates to the barley and to other small grains when the barley either matures or is killed by frosts. During the winter months the aphids multiply rapidly and do their greatest damage in this section to the fall and winter sown barley, sometimes weakening it to such an extent that very little grain is produced. In the cooler sections of the United States this aphid is found chiefly on late corn, broomcorn, and sorghums, rarely doing serious injury because of its late appearance.

TYPE AND EXTENT OF INJURY

It is difficult to estimate the amount of damage that may be done by this insect. It commonly attacks the corn in the North so late that little injury is possible except on the late corn. Here the heavily infested leaves turn yellow or red following the feeding and may shrivel and die, particularly if the weather is dry. According to Forbes (*13*), there is some evidence that the insect may at times prevent fertilization of the kernel by sucking the sap from the silk or pistillate flower and killing it before it has performed its function. A heavy infestation may also weaken the stalk and delay maturity to such an extent that the plants may be injured by frost.

Farther south corn is attacked much earlier in the season, so that more damage may be done. As has been cited by McColloch (*15*), another more common form of injury to corn in Kansas and southward is that the aphids, by feeding on the tassel, may prevent its function of producing pollen. Also the tassel occasionally becomes so gummed with honeydew as to prevent the shedding of the pollen that is produced. This honeydew forms one food of the adult of the corn ear worm (*Heliothis obsoleta* Fab.) and hence attracts great numbers of the moths to the field, thus being an indirect source of injury. Molds and rots often set in which weaken the stalk, some-

times resulting in the loss of the top and thus destroying the ear or at least reducing its size.

Broomcorn is sometimes considerably damaged by a reddened discoloration of the brush following the feeding puncture. A similar discoloration and small-sized grains frequently follow a heavy infestation of the heads of grain sorghum. Forbes (*13*) considered this to be due to a bacterial infection. Such infection has not yet been definitely shown, however, and in the light of recent work by Wadley (*20*) on the damage caused by the feeding of *Toxoptera graminum* Rond. it seems possible that the injury may be due to an enzyme injected by the aphid.

McColloch (*15*, *p. 91*) reports that in western Kansas in 1920 "the infestation resulted in shrinking the head, causing a loss of about 33 per cent in weight and 50 per cent in volume" on grain sorghums. Hayes (*14*) shows a rather serious loss in germination from heavily infested heads. The plant is sometimes weakened and the boot injured so that the head does not fully emerge and proper pollination becomes impossible. The heavily infested heads become covered with honeydew, and in humid weather molds and other fungi attack the honeydew, thus giving an unsightly appearance. Much stunting of the growth frequently attributed to dry weather is sometimes more properly due to the feeding of this insect.

The loss on barley in the South and Southwest often reaches considerable proportions. The late-sown barley is always injured more severely than that sown earlier in the season. The leaves become curled and sickly, and frequently an entire field has the appearance of suffering from drought. Occasionally the plants are yellowed and look as if they had been sun-scalded. At El Centro, Calif., more than 600 aphids were counted on one stalk, and a careful estimate indicated the presence of between 400 and 500 aphids on each stalk in three-fourths of the field. It is obvious that such an infestation would practically ruin the entire crop. On Harold Bell Wright's ranch at Meloland, Calif., the aphids were so abundant in 1912 as to cause the complete loss of a 10-acre field of barley. Mr. Wright, in a letter to the senior author, says: "The aphids have been so thick and their honeydew so abundant that one could not walk 10 steps in the field without having pants and shoes a mass of stickiness."

Although this aphid does not normally feed to any great extent on sugarcane, it does go to this crop occasionally, especially when its normal wild hosts in the field are destroyed in the process of cultivation. It has been shown by Brandes (*1*), Chardon and Veve (*6*), and others to be responsible for the dissemination of sugarcane mosaic, which causes a considerable loss to the sugar industry.

LIFE HISTORY

Sweepings of barley and other grains and thorough searches in the fields in the South and Southwest over a period of 20 years have failed to reveal males or oviparous females. The oviparous female has never been observed, or obtained by rearing, and the males have been reared in only a very few cases.

Forbes (*12*, *13*) discusses at some length his unsuccessful attempts to find sexual forms or eggs. From 1907 to 1912 E. O. G. Kelly spent considerable time in breeding work and searching in fields

and watching the flights of *Aphis maidis* in the fall in Kansas, but he found no evidence of sexes. Vickery and coworkers reared many thousands of specimens at Brownsville, Tex., without recording any true sexes, although in his notes Vickery described one specimen, secured in January, 1911, that might have proved to be a sexual form had he reared it to maturity. His description of this specimen agrees closely with that given later in this bulletin for the young of the male forms.

Wilbrink (*22*) and Van Breemen (*2*, *3*, *4*) in Java, and Vuillet and Vuillet (*19*) in the French Sudan did considerable breeding work, and each found only the viviparous forms occurring. In fact, with the exception of the few males found in the generation experiments at Tempe, Ariz., no sexual forms have ever been recorded.

From the latitude of northern Texas southward the species winters as viviparous females on barley and other small grains. The method of overwintering in the North is at present unknown. Less than 25 per cent of the aphids were able to withstand the unusual temperature of 13° F., which was recorded at Tempe, Ariz., in 1912. In localities where the temperature falls much below this point the aphid is not known to survive the winter.

Just how the aphid becomes so injurious in the North is not definitely known. It is possible, as suggested by Davis (*8*, *p. 144*), that it may migrate northward much as the green bug (*Toxoptera graminum* Rond.) does, but such migration has not been definitely proved. The writers have observed that at Tempe, Ariz., and San Antonio, Tex., the alate forms appear much more numerous during the six weeks following March 25, and again for six weeks following August 25, than at other times. A note made by the senior author at Tempe, Ariz., on April 19, 1917, is as follows:

> Alate spring migrants are in the air thick the past three days, and this morning they were especially numerous. At sunrise the air was alive with them, and the reflection of the sun upon their rapidly moving wings made a unique lighting effect.

Similar migrations were observed by Van Breemen (*2*, *3*, *4*) in Java. Forbes (*13*, *p. 125*) states: "The species makes its appearance in midsummer, our earliest date being July 9, when specimens were found on young leaves of corn. We have no record whatever to show whence it comes or where it lives preceding this time." This late appearance in the North adds weight to the theory that the species may migrate from the South.

In the summer the fully developed aphids are very small, often scarcely more than one-half to two-thirds the size found during cooler weather. Associated with this reduced size is a much shorter life and the production of a very small number of young.

CAGES USED IN LIFE-HISTORY STUDIES

Barley was found to be the most desirable host plant to use in cages, as it is one of the favorite food plants, is hardy enough to withstand all degrees of temperature imposed, and furnishes a small leaf surface which can be easily examined.

A single barley plant was allowed to grow near the center of a 6-inch flowerpot, and a 4-inch lantern globe with cloth top was

placed over it. The plant was pinched back from time to time to regulate its size. The cloth cover allowed sufficient ventilation to prevent excessive moisture from gathering inside the globe. (Fig. 4.)

DIFFICULTIES ENCOUNTERED

It was often difficult to examine the cages during cold weather because of the aphids' habit of crawling deep into the center whorl of the plant, making it almost impossible to count the number present without injuring either the plant or some of the aphids. The number could sometimes be determined by holding the plant between the observer and the sunlight or, better, a 40-watt electric light; the aphids would then appear as shadows within the whorl.

Perhaps the greatest difficulty encountered in the generation experiments was due to the tendency for the plant to develop a wilt dis-

FIGURE 4.—Cages used in life-history studies

ease under conditions of high temperature and humidity, such as prevailed in the spring. A plant that appeared healthy when the cage was examined on one day would often be wilted the next day and the aphids scattered beyond recovery.

Another serious difficulty was caused by a fungous disease which attacked the aphids and killed large numbers of them at times when the temperature and humidity were high. Fortunately for the continuity of the series, the female was not usually killed until she had produced one or more young, although she often died within a day or two thereafter. Since this disease was most prevalent during April, May, and June, when reproduction was at its height, the average number of young was considerably reduced.

GENERATION EXPERIMENTS

Losses from the various causes mentioned above made it impossible to carry all the generation experiments through the entire year. Of approximately 50 series of cages run at Tempe, Ariz., to determine the maximum number of generations by using the first-born each time, only 7 were carried through the entire year. Even in these

cases other individuals of the same age as those used to start the cage were occasionally substituted in order that the series might be continued through the year. Only two series were carried for more than a year, one of these for a year and nine months.

Approximately 30 series of cages were started to determine the minimum number of generations by using the last-born each time, but none was successfully carried through an entire year even with substitution. Five cages were carried successfully for 10 months or more and so gave an indication of about what could be expected. In these series 1,141 individuals were kept throughout their entire lives. The maximum age for these individuals was 86 days, and the maximum number of young was 95.

Table 2 summarizes only the few series of cages which were carried for 11 months or more for first-born generations and approximately 10 months for the last-born. The maximum number of generations in a year varies from 35 to 40, with an average of 37. If allowance is made for a probability of about 2 more generations during the approximate six weeks not shown for the last-born, the minimum number of generations would vary from 13 to 20, with an average of 16.

TABLE 2.—*Generation data*

Age		Maximum young	Average young	Generations	Time
Maximum	Average				
Days	*Days*	*Number*	*Number*	*Number*	
DETERMINED FROM FIRST-BORN					
61	22	57	16	36	1 year.
57	22	69	25	37	Do.
68	26	57	26	37	Do.
64	27	72	23	35	Do.
67	26	63	21	37	Do.
75	31	65	24	36	1 year, 24 days.
79	29	76	26	61	1 year, 9 months, 12 days.
55	28	75	29	35	11 months, 14 days.
62	26	65	35	38	11 months.
59	26	66	35	40	11 months, 14 days.
Mean 65.7	26.3	66.5	26	----------	
DETERMINED FROM LAST-BORN					
42	21	47	23	18	10 months, 5 days.
60	34	54	36	11	10 months, 7 days.
72	25	76	24	12	10 months, 11 days.
79	30	63	24	11	10 months, 3 days.
55	16	57	14	17	9 months, 26 days.
Mean 61.8	25.2	59.4	24.2	----------	

The milder winters and cooler summers occurring at Brownsville, Tex., enabled Vickery to carry 14 series of cages for one year and 12 series for two years for the maximum number of generations, and 9 series for one year and 4 series for two years for the minimum number of generations. He found the maximum number of generations in one year to range from 39 to 50, with an average of 45.1, and the minimum number to range from 16 to 20, with an average of 17.2.

The number of generations in the North would be much smaller owing to the short season. Davis (*8*, *p. 149*), working in Illinois, says: "* * * from my experiments, it may be definitely said that there were not more than 9 generations after June 26," the earliest date of its appearance.

LENGTH OF INSTARS

The length of the several instars varies considerably, depending on a number of factors, although temperature is the dominant one. Fourteen individuals were carried through to the adult stage and observed for molts during March and April, and nine individuals during July and August. (Table 3.) The observations were made at 6-hour intervals. These individuals molted four times, and one specimen molted five times.

TABLE 3.—*Length of instars in days*

First	Second	Third	Fourth	Fifth	Total
OBSERVATIONS DURING MARCH AND APRIL					
2.50	3.50	3	4	----------	13
3.25	2.50	4.25	5.25	----------	15.25
2.50	3.50	3	3	----------	12
2.50	1	5.50	4	----------	13
2.75	2.75	2	2.50	----------	10
2	3	2.50	4.50	----------	12
2.75	3.75	2.50	5	----------	14
1.50	1	2.50	2.25	3.75	11
3	2	2	3	----------	10
3	2.25	2.75	2	----------	10
2	1.75	2.25	2.75	----------	8.75
2	1	2.75	2	----------	7.75
3	1.25	2.25	2.50	----------	9
2.50	2	2	2.50	----------	9
Mean 2.51	2.25	2.80	3.23	----------	11.05
OBSERVATIONS DURING JULY AND AUGUST					
1.25	1	1.25	1.25	----------	4.75
1.25	1.75	1	1	----------	5
1.25	1	1.75	1	----------	5
1.50	1.50	1	2	----------	6
1.50	1	1	1	----------	4.50
1	1	1	1.50	----------	4.50
1	2	1	2	----------	6
1.50	1.50	1.50	2	----------	6.50
1.50	1.50	1	1	----------	5
Mean 1.30	1.36	1.16	1.41	----------	5.25

The time required to reach the adult stage varied from 4.50 days as a minimum in July and August to 15.25 days in March and April. Alate forms required a day or two longer than apterous forms. No record was made of molts during the winter months, but the generation cages show that the total length of the instars would have increased to from 18 to 22 days, depending on the temperature.

VIVIPAROUS FORMS

The viviparous forms have been fully described by Davis (*8*), and it seems unnecessary to repeat these descriptions here.

SEXUAL FORMS

The sexual forms of *A. maidis* occur very rarely in the United States, and thus far have not been recorded from any other country. Various entomological workers have spent much time and carried the species through many generations without having obtained a specimen of either of the sexes.

While running a series of generation experiments at Tempe, Ariz., in 1920, the junior author obtained two specimens that were later determined by A. C. Baker as alate males of *A. maidis*. Since that time 40 or more males have been reared by the same author. With the exception of 2 males born November 29, all were secured during December, January, and February. The writers have not yet been able to secure the oviparous females.

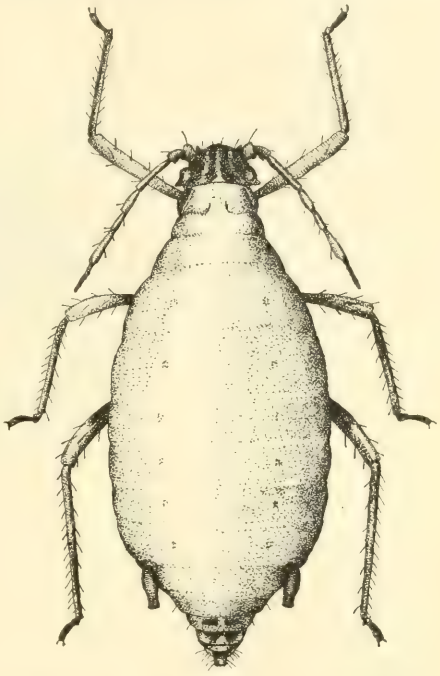

FIGURE 5.—Apterous viviparous female *Aphis maidis*

No definite statement can yet be made concerning the factors influencing the occurrence of sexual forms. The first 4 males produced were the first and second born of certain given females, while the next 8 males secured were the last 8 born of a single female. In another case there was an indiscriminate mixing of males and apterous and alate viviparous individuals after 36 normal viviparous young had been born. (Figs. 5 and 6.)

In each of the three seasons, 1919–20, 1921–22, and 1923–24, in which males were found, the average temperature ranged from nearly normal to 8.4 degrees above normal for each month, with no abnormally low temperatures (a minimum of 30° F.). During these three years 40 series of cages were run through the season, and males appeared in 6 of them. The average temperature during the winter of 1924–25 was also above normal, although there were occasional low temperatures, with a minimum of 23° F. Nineteen series of cages were run during this season without any sexual forms appearing. During the six years 1911 to 1917, 27 series of generations were carried through the winter seasons without sexual forms appearing. Four of these six seasons averaged below normal; the other two averaged above normal, although there were unusual cold spells in which the temperatures dropped to 27° F. While all the males thus far observed were secured during very mild winters, the number of cages under operation is too small to show definitely that temperature is a controlling factor. Other workers have carried *A. maidis* through the winter in greenhouses, in heated rooms,

and in the Tropics without producing sexual forms. There seems to be no correlation between the number of males secured and the prevailing humidity or a combination of temperature and humidity. The greatest number of specimens developed during two of the seasons when the work was carried on under an open shed where some of the light was cut off, but they were not secured in other seasons under the same shed. They also developed in a third season when the work was done in the open with full daylight. Other workers have carried them through in inclosed sheds and rooms where the light was greatly reduced without securing sexual forms, so that a reduction of daylight does not seem to account for this occurrence.

The writers have been unable to find any other factor or group of factors that may be said to influence the occurrence of sexual

FIGURE 6.—Alate viviparous female *Aphis maidis*

forms. It seems probable that in the process of evolution *Aphis maidis* has developed to a point where the sexual forms are no longer necessary and the species can indefinitely continue to reproduce parthenogenetically.

MALES

Unfortunately, no males were observed closely enough to permit definite conclusions concerning the number of instars, the length of each instar, etc. A general statement can be made, however, that males required from two to nine days longer to reach maturity than the normal apterous, viviparous female born at the same time.

In all but one case the males were recognized as different in some way from normal young as soon as they were found. The second time they were found they were retained to start a cage of first-borns and were not recognized as males until they became adults.

Since no technical description of the young male is available, it seems desirable to incorporate here some extracts from the notes

made by the junior author at the time the young were found. The first note appears on February 11, 1920, and is as follows: "Two larvae are found to-day. These are extremely dark colored." These two larvae were isolated for observation, and on March 1 appears the following:

Both are now winged adults. These are much more slender than the average winged female and the abdomen is much darker; the average winged female having a black thorax and a greenish abdomen while these have both thorax and abdomen black.

These two specimens were observed for a few days, then preserved in alcohol and sent to A. C. Baker, who determined them as alate males of *Aphis maidis*. Another note, under date of December 21, 1921, is as follows:

One young is so different that it is isolated to watch developments. It is of a dull black color, so that when first seen on a yellowed leaf I thought it dead. It is comparatively broad across the thorax, and the sides of the thorax and abdomen are parallel. The tip of the body does not extend beyond the cornicles at this time. (Age about 3 days.)

DESCRIPTION OF MALE APHIS MAIDIS (FIGS. 7, 8, 9, 10)

The following description is from five specimens reared by the junior author, which are now deposited in the United States National Museum (No. 19328).

Head and thorax black; abdomen dark bluish green, appearing almost black, with a slightly darker spot on the side of each abdominal segment. Antennae 6-segmented, reaching nearly to the cornicles. Third antennal segment with 12 to 47 circular sensoria irregularly distributed; fourth with 9 to 25 similar sensoria irregularly distributed; fifth with 6 to 15 sensoria; sixth with 1 large sensorium at the apex of the basal portion and none to 2 small sensoria on the basal portion. Legs black. Cornicles black, largest in the middle and somewhat dilated at the apex.

Measurements (average specimens in alcohol): Length of body, 1.456 mm; width, 0.572 mm; wing expanse, 6.29 mm. Antennae (Table 4), basal segment, 0.0624 mm; segment 2, 0.0624 mm; segment 3, 0.3299 mm; segment 4, 0.1788 mm; segment 5, 0.1726 mm; segment 6, 0.0936+0.2080 mm; total, 1.1077 mm. Cornicles, 0.104 mm.

TABLE 4.—*Measurements of male antennae*

Individual No.	Segment 1	Segment 2	Segment 3		Segment 4		Segment 5		Segment 6	
			Length	Sensoria	Length	Sensoria	Length	Sensoria	Length	Sensoria
	Mm	*Mm*	*Mm*	*Number*	*Mm*	*Number*	*Mm*	*Number*	*Mm*	*Number*
1	0.0624	0.0624	0.3288	47	0.1664	25	0.1456	6	0.104+0.2288	1
	.0624	.0624	.3288	34	.1664	24				
2	.0624	.0624	.3744	36	.1872	15	.2080	6	.104+.2496	3
	.0624	.0624	.2912	25	.1872	17	.1872	15	.104+.2288	
3	.0624	.0624	.3952	42						
	.0624	.0624	.3744	21						
4	.0624	.0624	.2288	12	.1072	9	.1456	6	(?)	(?)
	.0624	.0624								
5	.0624	.0624	[1].4784	[1]47			.1768	14	.0624+.1248	1

[1] Segments 3 and 4 united.

NATURAL CHECKS

Like many other injurious insects, *Aphis maidis* is ordinarily held in check by adverse weather conditions and the natural enemies which prey upon it. Often, however, weather conditions may be favorable for its rapid multiplication where its natural enemies are few in number, and then severe injury may be expected.

FIGURE 7.—Male *Aphis maidis*

FIGURE 8.—Antenna of male *Aphis maidis*

FIGURE 9.—Cornicle of male *Aphis maidis*

FIGURE 10.—Cauda of male *Aphis maidis*

ADVERSE WEATHER CONDITIONS

As has been shown previously, both extremes of temperature are detrimental to the welfare of this aphid. The aphids are unable to survive the cold winters of the North as viviparae even on the favored hosts. Less than 25 per cent were able to survive the unusual cold of 13° F., at Tempe, Ariz., in 1912. On the other hand, the extreme summer heat in the Southwest reduces the size of the aphids one-third to one-half, shortens the span of life, and greatly curtails the number of young produced.

Hard, beating rains frequently destroy large numbers of the aphids, although not so many of them as of many other species, because *Aphis maidis* is well protected within the plant.

Warm, humid weather is favorable to a fungous disease which often causes the death of large numbers of these aphids.

INSECT AND OTHER ENEMIES

Aphis maidis is attacked by a large number of natural enemies. In the United States alone the known list includes 13 coccinellids, 7 syrphids, 2 other Diptera, 2 lacewing flies, 1 hymenopteron, 1 reduviid, and many small spiders, several of which have not been specifically determined. Certain small lizards and birds also occasionally feed on this insect.

FIGURE 11.—*Hippodamia convergens: a*, Adult; *b*, pupa; *c*, larva. (Webster and Phillips)

LADYBIRD BEETLES

Probably a large percentage of the species of ladybird beetles can, and do at times, feed on *Aphis maidis*. Thirteen species have been recorded as feeding commonly on this aphid. Two species in particular, *Hippodamia convergens* Guer. (fig. 11) and *Ceratomegilla fuscilabris* Muls., are very widely distributed and are nearly always in evidence during an aphid outbreak. Both larvae and adults of this group feed on aphids and other soft-bodied insects.

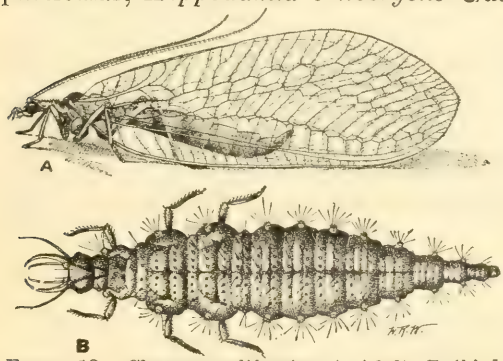

FIGURE 12.—*Chrysopa californica:* A, Adult; B, third instar. (Wildermuth)

In 1912 Vickery obtained the ladybird beetle *Chilomenes sexmaculata* Fab. from India and attempted to establish it near Brownsville, Tex., to help control this aphid. The beetles fed readily on these aphids, but the attempt seems to have failed, since no specimens have been recovered.

LACEWING FLIES

In the Southwest *Chrysopa californica* Coq. (fig. 12) is the most important of the neuropteron group. The senior author has carefully worked out the life history and habits of this insect and shown that it will eat from 75 to 150 or more mature aphids or from 400 to 500 aphids of all sizes during its lifetime. It feeds only during

the larval stages, grasping an aphid and completely draining it of its body contents before discarding it and taking another. In cage work the adults were not observed to feed; they lived only two or three days until the complement of eggs was laid.

SYRPHID FLIES

The larvae of syrphid flies form another important group of natural enemies of *Aphis maidis*. Seven species have been recorded as feeding on this aphid. Davidson (*7*) credits *Allograpta fracta* O. S. as being chiefly responsible during certain years for the control of *A. maidis* in the Imperial Valley of California. This species is also common in Texas, Oklahoma, and Kansas. Other species seem to be more common farther east.

FIGURE 13.—*Lysiphlebus testaceipes* (Cress). (Webster and Phillips)

INTERNAL PARASITES

The internal hymenopterous parasite *Lysiphlebus testaceipes* (Cress.) (fig. 13) is probably the most widely distributed and at the same time the most important parasite of *Aphis maidis* in the United States. Nearly every colony of aphids observed was found to have a number of infested individuals. While the weather remains warm entire colonies are destroyed, but during the cooler weather the aphids are able to more than hold their own with this parasite, as the temperature at which the parasite develops most readily is somewhat higher than that required by the aphid for rapid multiplication.

LIST OF INSECT ENEMIES OF APHIS MAIDIS FITCH

Coleoptera:
- *Adalia bipunctata* L.
- *Ceratomegilla fuscilabris* Muls.
- *Coccinella novemnotata* Hbst.
- *Cycloneda rubripennis* Casey
- *Cycloneda sanguinea* L.
- *Hippodamia convergens* Guer.
- *Hippodamia glacialis* Fab.
- *Hippodamia parenthesis* Say
- *Hyperaspis signata* Oliv.
- *Olla abdominalis* Say
- *Psyllobora 20-maculata* Say
- *Rodolia cardinalis* (Muls.)
- *Scymnus* sp.

Diptera:
- Syrphids—
  - *Allograpta fracta* O. S.
  - *Allograpta obliqua* Say

Diptera—Continued.
- Syrphids—Continued.
  - *Baccha clavata* Fab.
  - *Eupeodes volucris* O. S.
  - *Mesogramma polita* Say
  - *Sphaerophoria cylindrica* Say
  - *Syrphus americanus* Wied.
- Other Diptera—
  - *Aphidoletes meridionalis* Felt
  - *Leucopis nigricornis* Egger

Lacewing flies:
- *Chrysopa californica* Coq.
- *Chrysopa* sp.

Hymenoptera:
- *Lysiphlebus testaceipes* (Cress.)

Hemiptera:
- *Reduviolus ferus* L.

CONTROL

TIME OF PLANTING

Since this insect does its greatest damage to late corn and sorghums in the North and to late-planted barley in the South, it is obvious that much can be accomplished in the way of reducing the injury by early planting and by thorough cultivation, where possible, to hasten the maturity of the crop. In the North early-planted corn usually is nearly mature before the aphid becomes abundant enough to injure the crop seriously. The early crops are not so succulent as the later planted crops and are not so attractive to the migrant forms. Early-planted barley is seldom hurt in the South, although the late planting is often seriously injured.

Any condition which causes the crop to grow in a thrifty manner will reduce the damage from this insect. Fields that are to be planted to crops susceptible to injury from this insect should be well tilled, preferably by deep plowing and thorough preparation of the seed bed, and they also should be maintained in a high state of fertility. Attention to these details will produce a rapidly growing crop and one that will outgrow much of the damage that may be caused by the feeding of these little insects. It is lack of this thrift and rapid growth in late-planted barley that enables the insect to cause serious damage in such fields.

PASTURING

In the South and Southwest barley is commonly sown in the fall and pastured during the winter. This pasturing is of threefold benefit, in that it supplies an abundance of green feed, causes a greater tillering of the plant, and at the same time helps to control the aphid. The aphid crawls deep into the whorl of the plant and is eaten by the cattle along with its host plant. When thus located, the insect has but little opportunity to fall from the plants while the stock are grazing on them. Thus, even a heavily infested field may be almost completely freed of the pest.

SPRAYING AND DUSTING

Although it is possible to kill many of the aphids on barley by spraying or dusting with insecticides, the comparatively low value of the crop and the high cost of the operation make this method inadvisable as an ordinary procedure. On the grain sorghums and corn the aphids hide in the head and deep within the growing tips, where it is difficult for ordinary sprays to reach them in an efficient manner.

SUMMARY

Aphis maidis was described by Fitch in 1856 and was confused with (*Aphis*) *Anuraphis maidi-radicis* Forbes until 1891, when Forbes showed the two to be distinct species.

Aphis maidis is quite generally distributed throughout the world between the parallels of 40° N. and 40° S.

It does its greatest damage in the United States when feeding upon barley, grain sorghums, and corn, and in the transmission of the mosaic diseases on sugarcane.

It is not known how or whether this aphid overwinters in the North. It has been suggested that it may migrate from the South.

Cage records show the maximum number of generations to vary from 9 in central Illinois to from 35 to 41 at Tempe, Ariz., and from 39 to 50 at Brownsville, Tex.

Males are recorded for the first time (Tempe, Ariz.) and are illustrated and described herein.

This insect can be controlled on corn and grain sorghums by early planting and on barley by early planting and pasturing the infested fields in case of an outbreak.

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TECHNICAL BULLETIN NO. 305 JULY, 1932

THE STRENGTH AND RELATED PROPERTIES OF REDWOOD

BY

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AND

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By R. F. LUXFORD,[1] *Associate Engineer*, and L. J. MARKWARDT, *Senior Engineer*, *Forest Products Laboratory*,[2] *Branch of Research, Forest Service*

CONTENTS

	Page
Introduction	2
Purpose	3
Nature of studies	3
Specific gravity survey	3
Specific gravity and variation	4
Specific gravity as affected by distance from pith	5
Specific gravity as affected by height in tree	6
Specific gravity variation among trees	6
Specific gravity as affected by site classification	8
Specific gravity as related to region of growth	9
Specific gravity as related to rate of growth	11
Effect of specific gravity on the utility of second-growth redwood	11
Description of test material and method of testing for strength	12
Results of strength tests on virgin-growth redwood	13
Results of strength tests on second-growth redwood	16
Factors affecting the properties and uses of redwood	16
Relation between specific gravity and strength	16
Relation between moisture and strength	20
Strength as related to height in tree	20
Moisture distribution within the tree	20
Properties as affected by extractives	21
Radial and tangential shrinkage	22
Compression wood and endwise shrinkage	23
Comparison of the strength of compression wood and normal redwood	24
Summary	25
Appendix	25
Detailed data from the specific gravity survey	25
Detailed data on strength and associated properties of redwood	34
Explanation of terms and methods employed	41
Literature cited	48

INTRODUCTION

Redwood is one of the important commercial woods of the United States. The combination of desirable qualities, including relatively high mechanical properties, medium weight, low shrinkage, ease of working, and high resistance to decay enables redwood to meet the requirements of many special as well as ordinary uses, thus giving it a high utility value.

[1] Acknowledgment is made of the cooperation and assistance of the California Redwood Association in this study, particularly that of the Pacific Lumber Co. and the Union Lumber Co.; also of that of Aldo Leopold, formerly of the Forest Service. The valuable assistance in the study rendered by the following members of the Forest Service: J. A. Newlin, B. H. Paul, A. Koehler, M. Y. Pillow, of the Forest Products Laboratory, and C. L. Hill, of the California Forest Experiment Station, is gratefully acknowledged; as are also photographs contributed by the Save-the-Redwoods League.

[2] Maintained by the U. S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

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The redwood, as found in the virgin stands, is one of the largest trees of the world. It is long-lived, reaching an age of 1,300 years or more, and commonly attains a diameter of 5 to 10 feet, and a height of over 250 feet. (Pls. 1 to 3.) Because of its great size, the tree yields a high percentage of clear lumber.

The natural range of redwood is confined to a relatively narrow belt of northern California, extending about 500 miles along the coast and from 10 to 30 miles inland, and in addition there is a small area of some commercial importance south of San Francisco. Redwood grows at elevations ranging from sea level to about 3,000

FIGURE 1.—Commercially important range of redwood

feet. The commercially important range of redwood is about 300 miles in length, as indicated by the shaded area in Figure 1. The redwood region is characterized by abundant atmospheric moisture throughout most of the year (*3*).[3]

Redwood (*Sequoia sempervirens* (Lambert) Endlicher) should not be confused with big tree (*S. washingtoniana* (Winslow) Sudworth), a closely related but distinct species whose range is confined to the west side of the Sierra Nevada Mountains at elevations from 5,000 to 8,500 feet. In general, the big tree is of larger diameter

[3] Italic numbers in parentheses refer to Literature Cited, p. 48.

REDWOOD TREES ARE LONG LIVED, FREQUENTLY REACHING AN AGE OF 1,300 YEARS OR MORE

The section shown is from a tree 864 years old.

EXAMPLES OF VIRGIN-GROWTH REDWOOD GROWN UNDER FAVORABLE CONDITIONS

Redwood, as found in the virgin stands, is one of the largest trees of the world, commonly attaining a diameter of 5 to 10 feet.

and attains a greater age than the redwood but is not now of commercial importance (*13*).

The stand of virgin redwood was estimated in 1920 at about 72,000,000,000 feet, board measure (*14*), and the annual cut since then has been about 500,000,000 board feet. Although the exhaustion of virgin stands is not to be shortly anticipated, some operators have given and are giving thought to reproduction on cut-over areas, and are looking forward to continued production from second-growth stands. Since most second-growth redwood has ample growing space in its early years, the wood put on in early life is of more rapid growth, weaker, and contains more knots than the virgin-growth redwood that has grown slower under normal forest competition throughout its entire life. Economic considerations will no doubt require that the second-growth stands of redwood be cut before the competition within the stand is sufficient to result in the formation of wood comparable to that of virgin growth.

PURPOSE

The purpose of this bulletin is to present information on the physical and mechanical properties of redwood. Such information is of value to architects, engineers, manufacturers, lumbermen, and others requiring detailed information on the properties of redwood. In addition, it should be of aid to foresters contemplating management plans for reforestation by affording a comparison of the properties of second-growth redwood produced under widely different growth conditions with those of virgin-growth material.

NATURE OF STUDIES

The information on redwood presented in this bulletin resulted from an intensive sampling in the field of trees from different sites and localities for specific gravity, and from selected typical logs that were sent to the Forest Products Laboratory for comprehensive strength tests. Hence the study is discussed under two divisions; namely, (1) specific-gravity survey and (2) strength and related properties.

The specific gravity survey consisted of determining the specific gravity of specimens taken from the pith to the circumference and at intervals from the butt to the top of each of a number of redwood trees from different sites and localities.

The study of properties consisted of standard strength tests on small, clear specimens of virgin-growth and second-growth redwood from Humboldt and Mendocino Counties, Calif. In addition, information was obtained on shrinkage, the abnormal wood known as compression wood, the distribution of moisture within the tree, the effect of moisture on the strength of the wood, and the influence of substances naturally present in the wood, called extractives (p. 21).

SPECIFIC GRAVITY SURVEY

The specific gravity (p. 46) determinations were made on many small specimens from each of 56 virgin-growth and 42 second-growth trees. The trees were selected in different localities from sites (p. 46)

that covered the range of growth conditions. The site classes for virgin redwood were determined in accordance with accepted silvicultural practice by the total height development of the dominant trees. The average height of the dominant trees on Site I was 251 feet and over; on Site II, 211 to 250 feet; on Site III, 171 to 210 feet; on Site IV, 131 to 170 feet; and on Site V, 130 feet and under. With second-growth redwood the site classes were based on the age and height development of the dominant and codominant trees (*2*). Of the second-growth trees from Mendocino County, three were from open stands, which permitted unrestricted crown development; the others were from normally well-stocked stands. (Pl. 4.) The second-growth trees from Humboldt County were all from the same stand.

SPECIFIC GRAVITY AND VARIATION

Table 1 gives the average results of the specific gravity determinations for virgin-growth redwood, and affords a means of comparing material from different sites in Humboldt and Mendocino Counties. Table 2 presents the average results of the specific gravity determinations of virgin-growth and of second-growth redwood without regard to source of material.

TABLE 1.—*Results of specific gravity determinations, by lots from different sites of virgin-growth redwood*

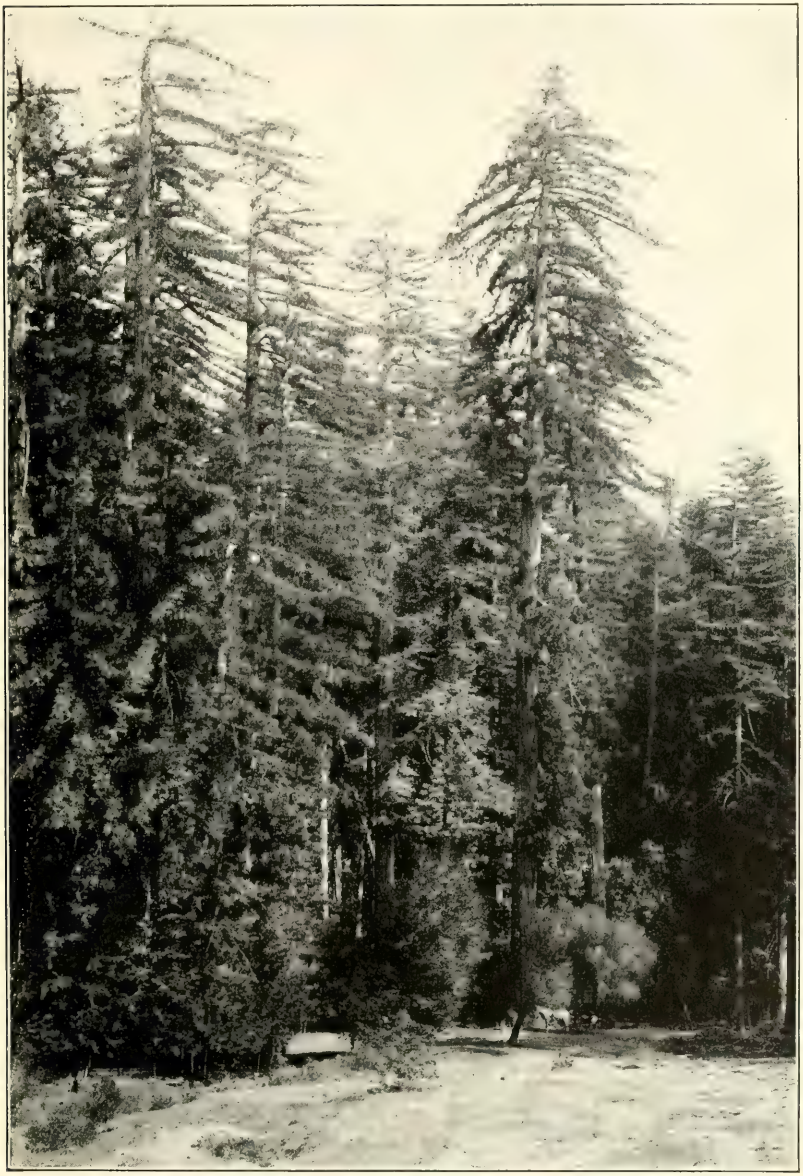
Place of growth	Lot No.	Site class No.	Trees	Specimens	Average specific gravity [1]	Probable variation of—	
						Individual tree from average	Individual specimen from average
			Number	*Number*		*Per cent*	*Per cent*
Humboldt County	3	I	5	452	0.365	8.16	9.69
Do	3	II	4	312	.364	6.90	8.21
Do	3	III	4	168	.375	3.22	9.34
Do	3	III	6	567	.364	8.30	12.15
Do	3	III	5	399	.356	9.00	11.94
Do	3	IV	5	339	.357	5.47	9.73
Total or average	....	I–IV	29	2,237	.363	5.99	10.60
Mendocino County	2	II	5	467	.388	2.95	9.20
Do	2	II	2	174	.393	----------	11.21
Do	1	III	5	357	.380	7.20	11.17
Do	2	III	5	302	.373	4.33	9.82
Do	1	IV	5	234	.374	1.51	9.86
Do	2	IV	5	275	.415	2.97	10.79
Total or average	....	II–IV	27	1,809	.387	5.00	10.36

[1] Based on the weight of the oven-dry wood and the volume when green.

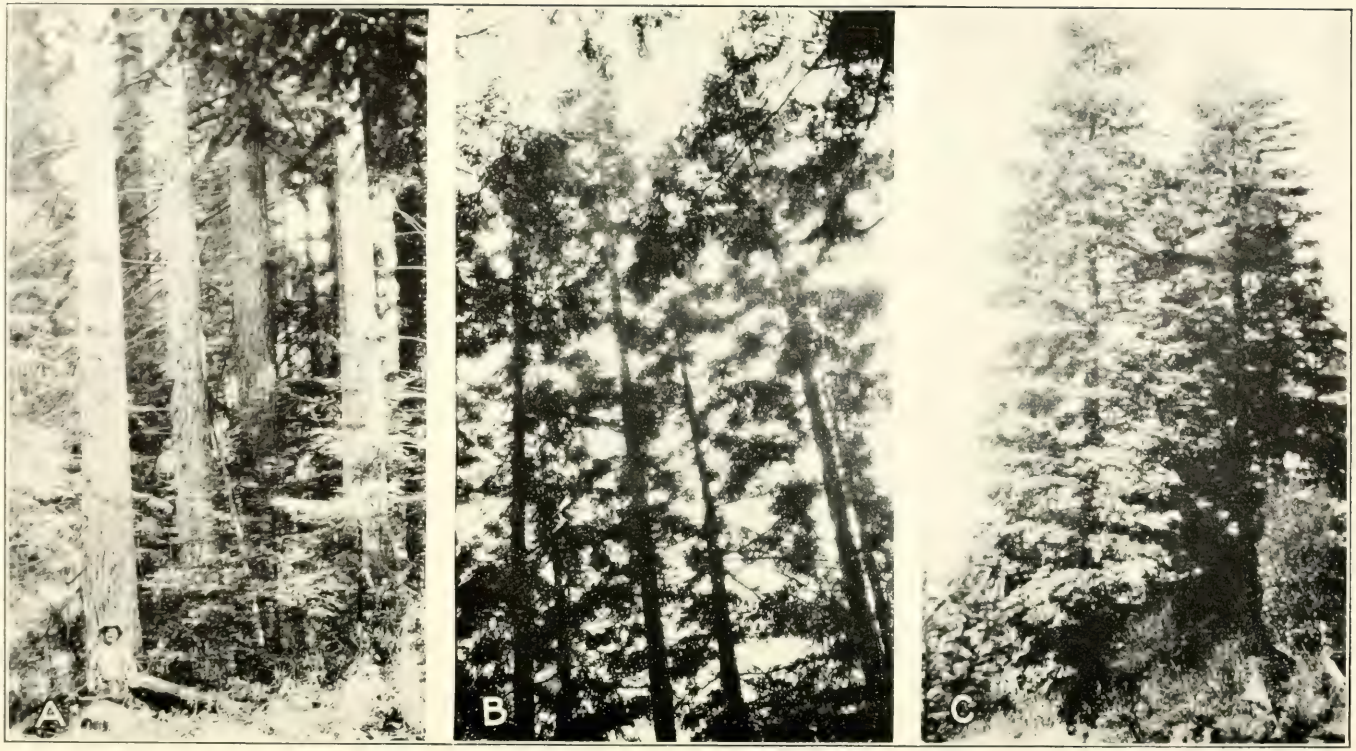
TABLE 2.—*Results of specific gravity determinations of virgin-growth and second-growth redwood*

Type of growth	Trees	Specimens	Average specific gravity [1]	Probable variation of—	
				Individual tree from average	Individual specimen from average
	Number	*Number*		*Per cent*	*Per cent*
Virgin growth	56	1,046	0.374	5.51	10.67
Second growth, closely grown	31	720	.356	4.10	8.17
Second growth, openly grown	11	267	.318	4.98	7.98

[1] Based on the weight of the oven-dry wood and the volume when green.



REDWOODS GROW TO GREAT HEIGHTS, MANY EXCEEDING 250 FEET



SECOND-GROWTH REDWOOD

A, Trunks of closely grown second-growth redwood; B, crowns of closely grown second-growth redwood; C, openly grown second-growth redwood.

The last two columns of Tables 1 and 2 are, respectively, percentage figures on the estimated probable variation in specific gravity of an individual tree as a whole from the corresponding average, and of an individual specimen of a tree from the same average. The probable variation is a value such that there is an even chance that a random specimen will not be above or below the average by more than this amount. For example, the figure 10.67 per cent, given in Table 2 as the probable variation in specific gravity of an individual specimen of virgin-grown redwood, means that there is 1 chance in 4 that a small specimen selected at random will have a specific gravity of less than 0.334, that is, $0.374-(0.1067\times0.374)$; 2 chances in 4 that it will be between 0.334 and 0.414, and 1 chance in 4 that it will be greater than 0.414. Expressed in another way, about one-half of the specimens from the virgin-growth redwood had a specific gravity between 0.334 and 0.414, the other half being divided about equally above and below these limits.

The estimated probable variation in specific gravity of an individual virgin-growth redwood tree from the average of all trees examined for the species was 5.54 per cent.

The estimated probable variation in specific gravity for an individual tree and for an individual specimen of second-growth redwood was less than for virgin growth. (Table 2.) This may, perhaps, be accounted for by the smaller size of the second-growth trees and the likelihood that because of their younger age they had not encountered the range of growth conditions experienced by the virgin-growth trees. In addition, the greater amount of extractives in the virgin-growth redwood was also a contributory factor.

Although definite information is presented on the variability of redwood, it should be noted that variability is not a characteristic of redwood alone but is common to all woods, and in fact all material. It is important to recognize in the manufacture, grading, seasoning, and selection of wood for different uses that all species exhibit variations in the properties of individual pieces, but it is even more important to know something of the extent of these variations. The information presented on the magnitude of variation in the properties of redwood, therefore, should be of particular value in the utilization of this species, since by a careful selection and classification of material of different characteristics and properties, the variability of wood, which is usually regarded as a liability, can, within limits, be made an asset. For example, the dense redwood is preferable for structural timbers, whereas the lighter weight, slow-growth redwood is preferable for such purposes as pattern stock.

SPECIFIC GRAVITY AS AFFECTED BY DISTANCE FROM PITH

Large differences were observed in the specific gravity of redwood within cross sections of the tree at any given height. In some virgin-growth trees, at a given height, a gradual decrease in specific gravity occurred in the heartwood from the pith toward the circumference, in others an increase took place, whereas in others there was but little change. (Fig. 2.) Toward the upper end of the merchantable length, however, the wood near the circumference was generally lighter in weight than at the pith. (Fig. 3.) The sapwood throughout the virgin-growth trees was consistently lighter in weight than

the adjoining heartwood, apparently because of the higher content of extractives in the heartwood. The highest and lowest specific gravities of small specimens found in a single tree of virgin growth were 0.518 and 0.210, respectively, both samples coming from the butt cut.

SPECIFIC GRAVITY AS AFFECTED BY HEIGHT IN TREE

The wood at the base of the redwood trees (stump height) was found to be higher in specific gravity than that farther up the stem. (Fig. 4.) The decrease in specific gravity with increasing height in tree for virgin redwood was fairly rapid over the lower half of

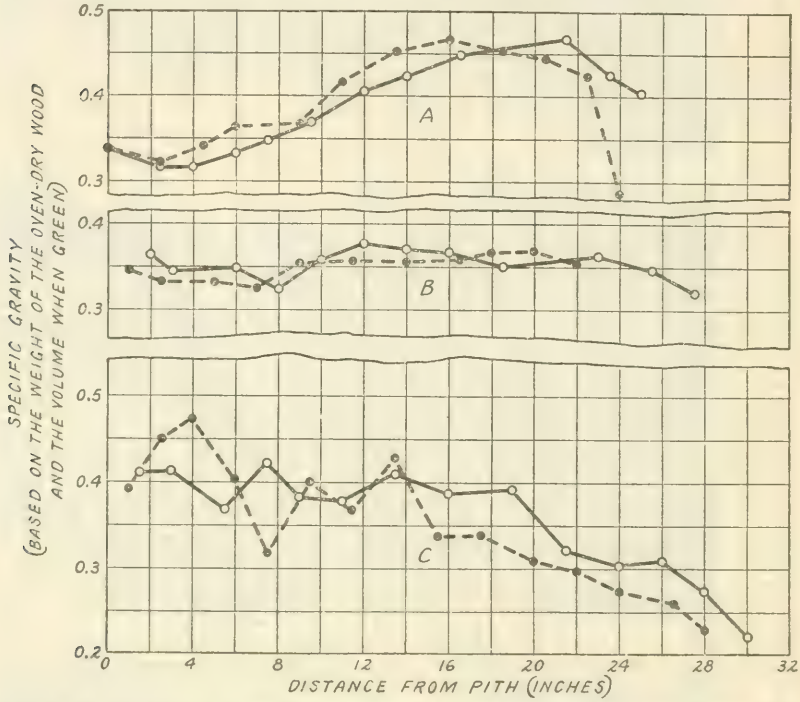


FIGURE 2.—Variation of specific gravity with distance from the pith for three different virgin-growth redwood trees at a height of 20 to 30 feet above the ground, showing (*A*) increase in specific gravity with distance from pith for greater part of diameter (*B*) little or no change, and (*C*) decrease. Each curve is distinguished by full and dotted lines representing specimens taken from opposite sides of the pith

the merchantable length and more gradual toward the top. The average difference in specific gravity of butt and top logs was about 15 per cent, which is sufficient to permit a judicious selection of material in manufacture to meet better the use requirements of service. For example, structural material that is cut from the lower logs of virgin-growth redwood will, for given defect limitations, average higher in strength than that cut from logs higher in the tree.

SPECIFIC GRAVITY VARIATION AMONG TREES

In addition to the variation of wood from different parts of the same tree, redwood, like wood of other species, showed a considerable

difference in specific gravity among different trees. The greatest observed difference in average specific gravity between individual trees of virgin-growth redwood from a single site was 25 per cent, which was based on the heaviest tree (fig. 5), whereas the greatest

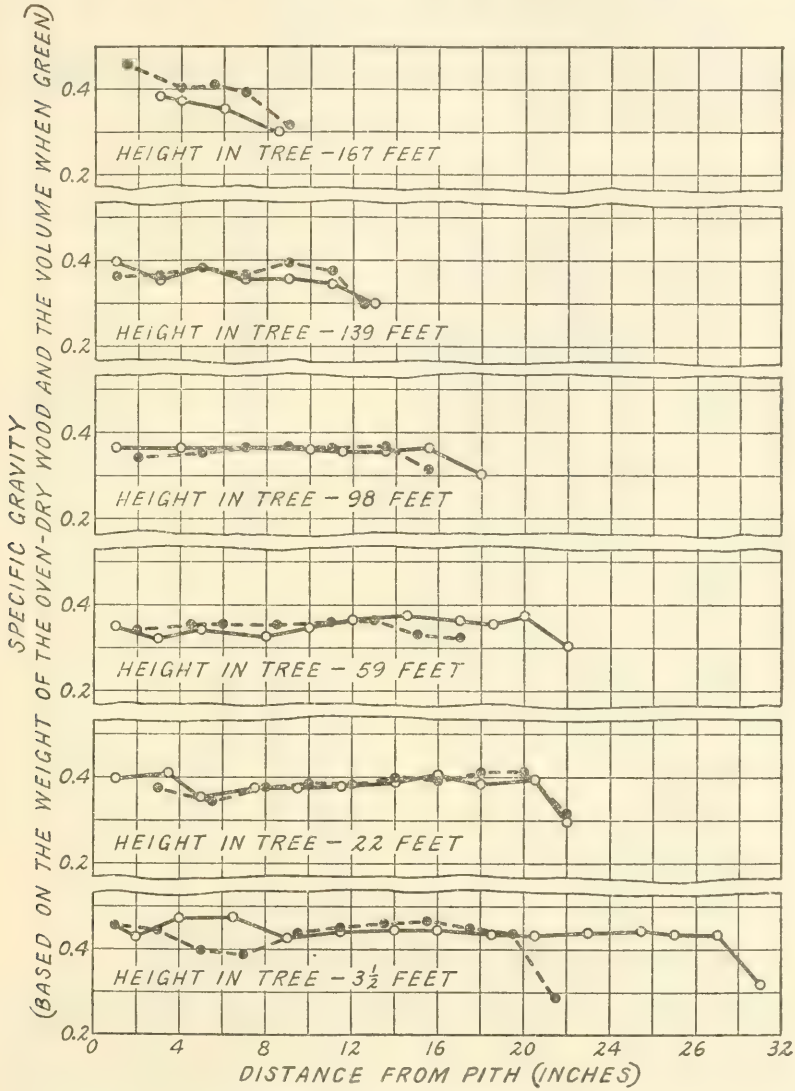


FIGURE 3.—Variation in specific gravity with distance from the pith for different heights in a selected virgin-growth redwood tree. The sharply downward trend at the outer part of the curves is due to the lower specific gravity of the sapwood as compared with the adjoining heartwood. The two curves for each height distinguished by full and dotted lines represent specimens taken from opposite sides of the pith

difference between individual trees throughout the entire range was only 30 per cent. The two trees representing these extremes were from the same county. The data indicate that growth conditions as affecting individual trees within a site and perhaps in-

herent differences in strains or types of trees are of greater importance in causing variations in virgin-growth redwood than geographical location within the normal range.

SPECIFIC GRAVITY AS AFFECTED BY SITE CLASSIFICATION

No definite relation was apparent between the conditions under which the redwood trees were grown, as indicated by the site classifi-

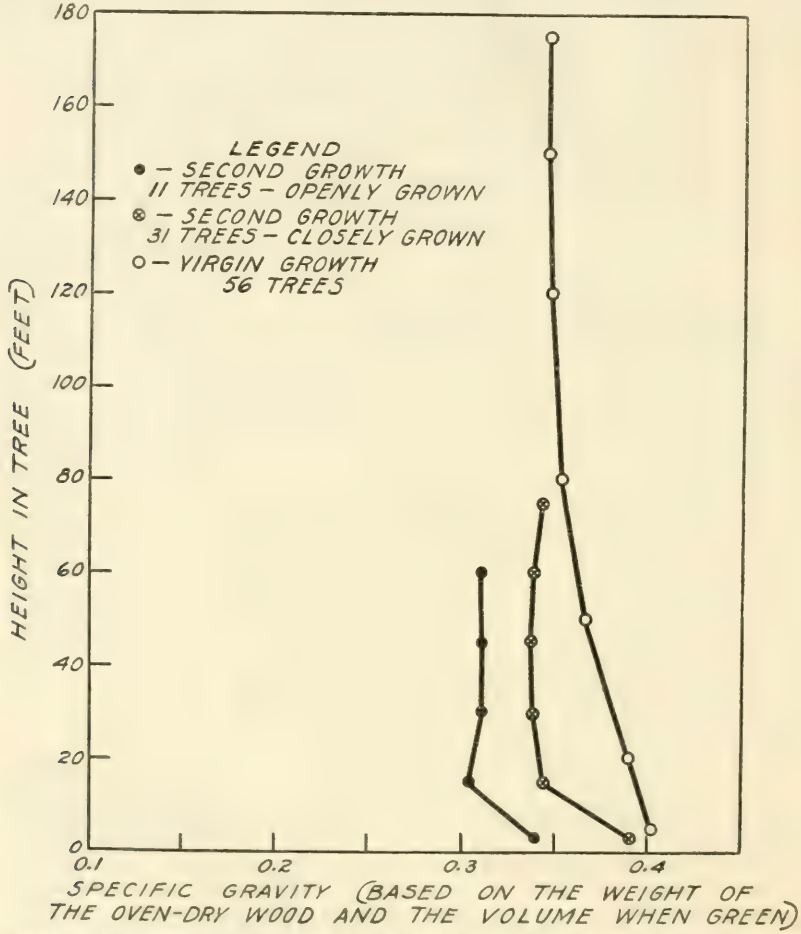


FIGURE 4.—Variation in specific gravity with height in tree for virgin-growth and second growth redwood. Curves are the average for all trees of each type studied

cation number (p. 4), and the specific gravity of the wood. The average specific gravity values of all the virgin-growth redwood trees from Humboldt County were 0.371, 0.370, 0.367, and 0.361 for Sites I, II, III, IV, and from Mendocino County 0.387, 0.384, and 0.394 for Sites II, III, IV, respectively. (Fig. 6.) If the site quality class is a factor in influencing the specific gravity of redwood, the influence on the material sampled was so small that it is obscured by other factors. For example, the extent to which a tree is crowded has

a marked influence on the character of the wood produced, as shown by the fact that in the second-growth redwood the closely grown small-crowned trees were approximately 10 per cent higher in average specific gravity than the large-crowned openly grown trees (*11*).

SPECIFIC GRAVITY AS RELATED TO REGION OF GROWTH

The influence of region of growth on the specific-gravity and strength properties, although known to be of appreciable signifi-

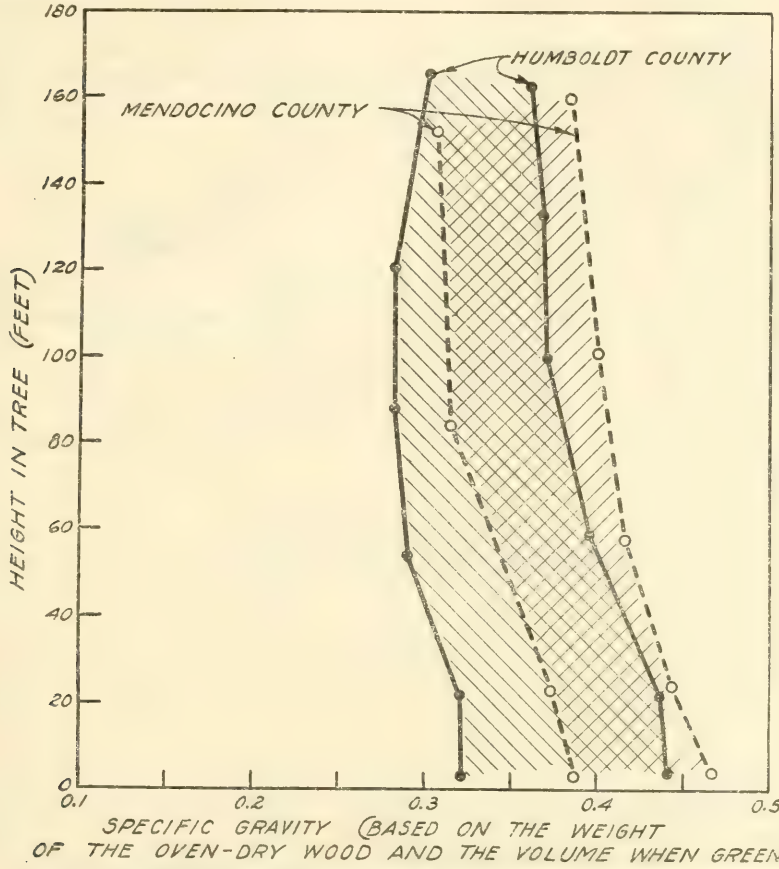


FIGURE 5.—Maximum range in the average specific gravity at various heights of individual virgin-growth redwood trees from single sites in Mendocino and Humboldt Counties

cance in some species, is often overestimated. However, producers have frequently recognized some difference in properties of virgin-growth redwood from the two principal producing regions, Humboldt and Mendocino Counties. The virgin-growth redwood from Mendocino County which was studied had an average specific gravity of 0.387; that from Humboldt County 0.363, the difference being about 6 per cent. (Table 1.) Because of the large differences in individual pieces from the same tree the average difference in specific

gravity between counties gives no assurance that in small shipments lighter or heavier material will be obtained from one county than from the other. It would appear, however, from the information presented here that large shipments of virgin-growth redwood lum-

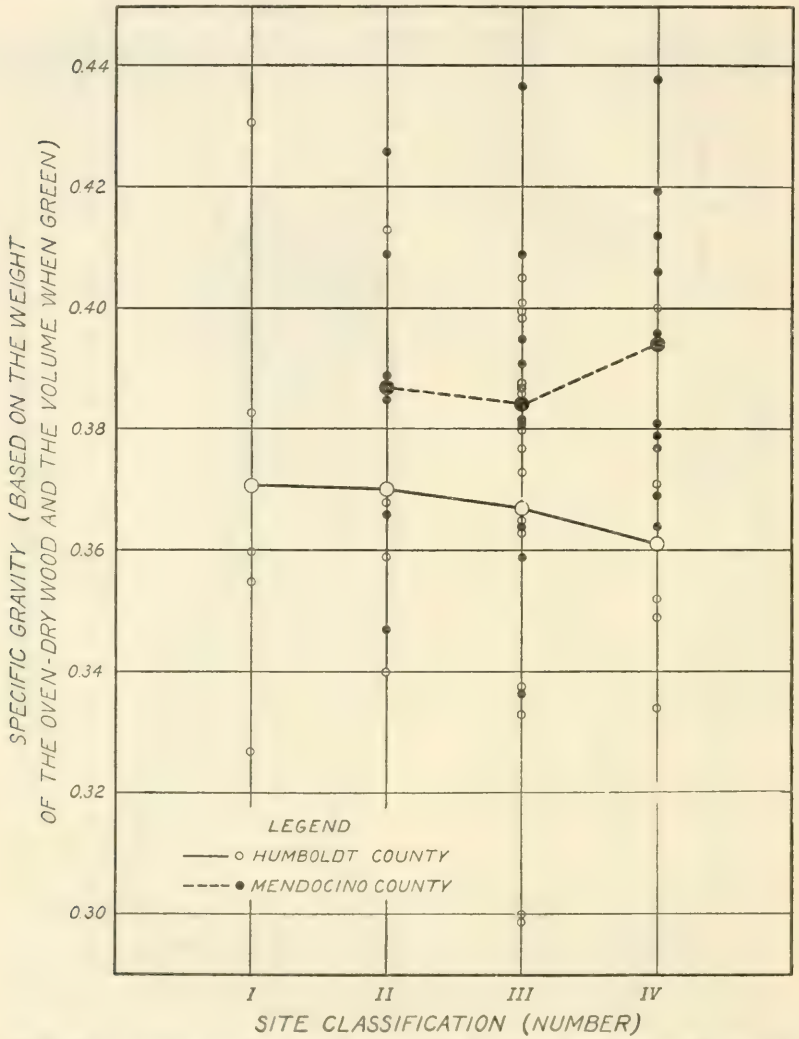


FIGURE 6.—Average specific gravity of individual virgin-growth redwood trees by site classes for Humboldt and Mendocino Counties. The full curve represents the average specific gravity of all trees for each site for Humboldt County and the dotted curve for Mendocino County. A site classified as I has dominant trees 251 feet or over; Site II, 211 to 250 feet; Site III, 171 to 210 feet; Site IV, 131 to 170 feet

ber from Mendocino County would average slightly higher in specific gravity than those from Humboldt County.

There was no significant difference in the average specific gravity of second-growth redwood from Humboldt and Mendocino Counties.

SPECIFIC GRAVITY AS RELATED TO RATE OF GROWTH

Figure 7 shows the relation between specific gravity and rate of growth in the heartwood. Rate of growth is represented by the number of annual rings per inch; the greater the number of rings per inch, the slower the growth rate. (Pl. 5.)

In general, the highest specific gravity is found in redwood having between 9 and 30 rings per inch. Low specific gravity is most commonly associated with exceptionally fast and exceedingly slow growth (*4*). Very slow growth often occurs in the outer portion of mature virgin trees.

Virgin-growth redwood from Humboldt County was found to be lighter in weight for the same rate of growth than that from Mendocino County. Second-growth redwood, on the other hand, showed practically the same relation between rate of growth and specific gravity in one county as in the other.

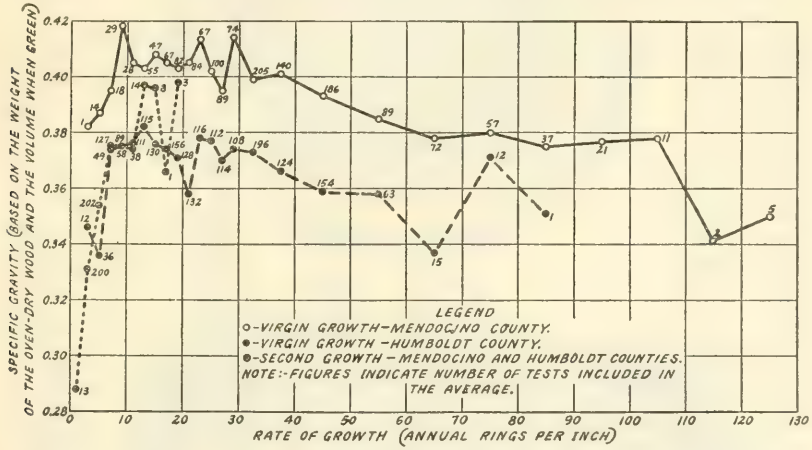


FIGURE 7.—Relation between specific gravity and rate of growth of the heartwood of redwood

EFFECT OF SPECIFIC GRAVITY ON THE UTILITY OF SECOND-GROWTH REDWOOD

The average specific gravity of second-growth redwood was less than that of virgin-growth material. The closely grown second-growth trees were about 5 per cent lower and the openly grown second-growth trees about 15 per cent lower in average specific gravity than the virgin growth. (Fig. 8.)

The significance of these differences naturally depends on the ultimate use of the wood, and it is obviously difficult to predict trends in consumption to arrive at the use requirements of the future. Considering the tree from the standpoint of structural timber, and to some extent of lumber, the advantage of wood of closely grown material over that from the openly spaced reproduction is apparent. Aside from the higher specific gravity of the clear wood of virgin-growth redwood, it is of course evident that young second-growth trees, because of the prevalence of limbs, can not be expected to yield so high a grade of timber or lumber as the virgin-growth material.

DESCRIPTION OF TEST MATERIAL AND METHOD OF TESTING FOR STRENGTH

The trees used for the strength tests were selected in the woods so as to be representative of the average and the range in specific gravity of redwood, as previously determined by the specific gravity survey. (P. 3.) Logs from trees selected in this manner give

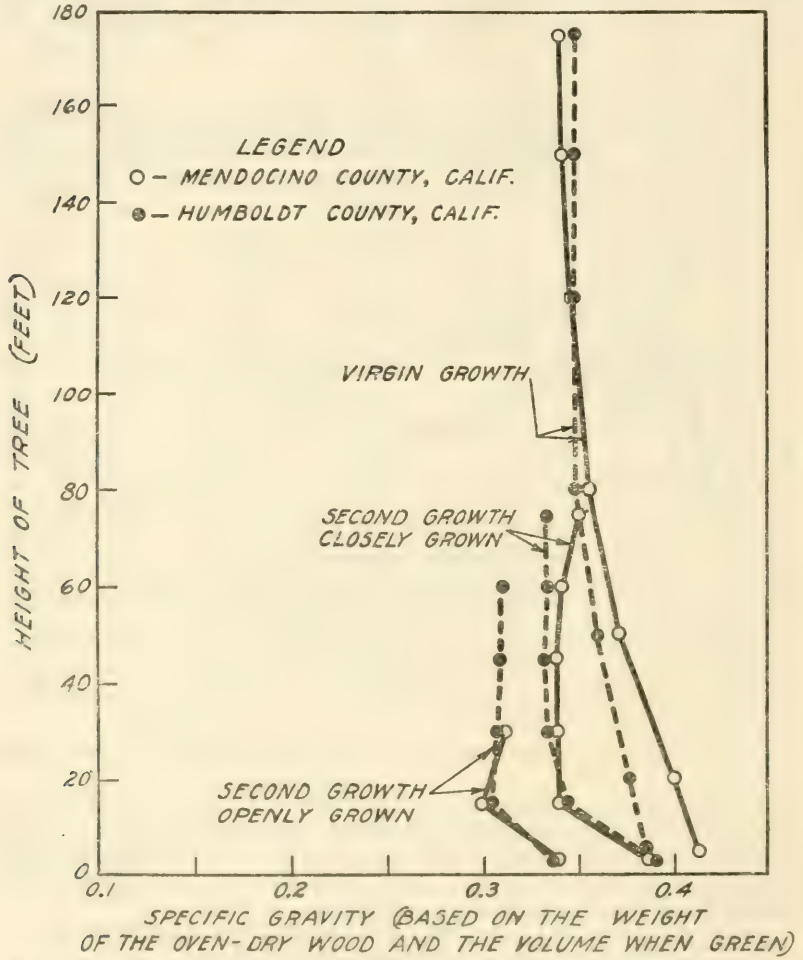
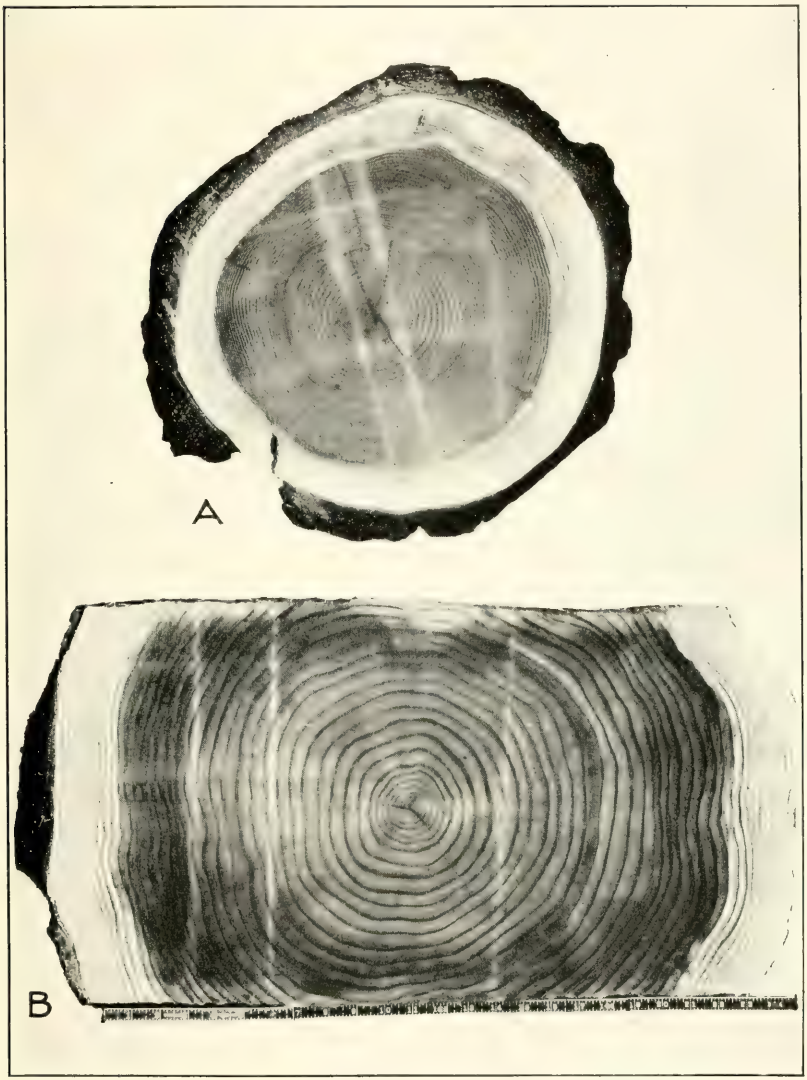


FIGURE 8.—Variation in average specific gravity by counties and height in tree for virgin growth and second growth redwood

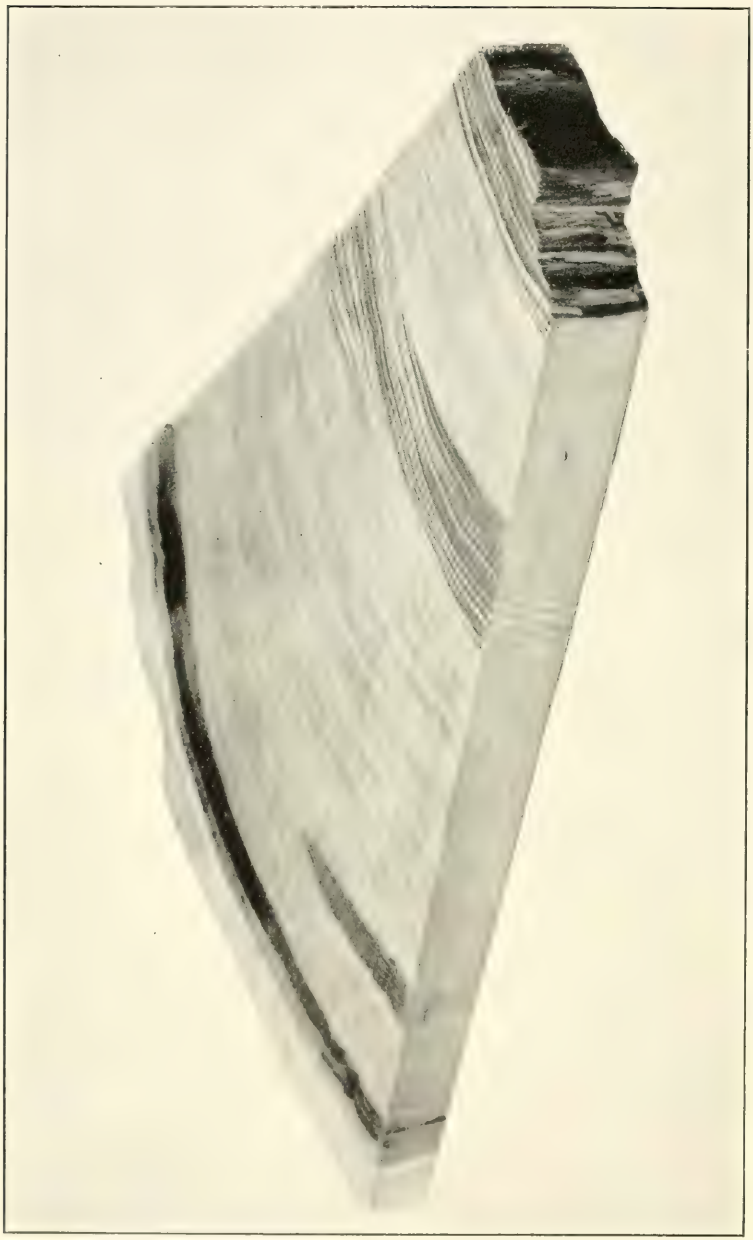
strength data considered more representative of redwood as a species than that from the same number of logs taken at random. Both virgin-growth and second-growth material from Humboldt and Mendocino counties were included in the strength study. The logs were shipped in a green condition to the Forest Products Laboratory where they were cut into small, clear specimens for testing.

A complete series of standard strength and related tests (*1*) was made on the redwood in both the green and air-dry condition. The



CROSS-SECTIONAL VIEW OF TWO SPECIMENS OF SECOND-GROWTH REDWOOD, BOTH AT SAME SCALE, EXHIBITING A LARGE DIFFERENCE IN RATE OF GROWTH AS SHOWN BY THE WIDTH OF THE ANNUAL RINGS

A, Closely grown second-growth redwood. B, Openly grown second-growth redwood.



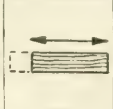
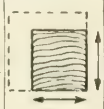
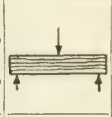
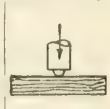
THE DARKER AREAS SHOWN IN THIS REDWOOD SECTION ARE COMPRESSION WOOD

tests included specific gravity, shrinkage, static bending, impact bending, compression parallel to grain, compression perpendicular to grain, tension perpendicular to grain, hardness, and toughness.

RESULTS OF STRENGTH TESTS ON VIRGIN-GROWTH REDWOOD

Tables 3 and 4 present the average results of strength tests on small, clear specimens of virgin-growth redwood. Table 3, in addition to presenting comparative strength values for redwood, includes strength figures for a number of other commercial softwoods of the United States with which comparison may be desired. The strength figures are expressed as percentages, redwood being taken as 100 per cent. The comparative strength figures for redwood in Table 3 are obtained by making certain combinations of the mechanical properties given in Table 4. The comparative strength figures are based on tests of both green and air-dried wood, and consequently represent a combination of moisture conditions. A complete discussion of the method of determining the comparative strength figures, together with the data on other species, is given in United States Department of Agriculture Technical Bulletin 158 (*8*). Because the values for redwood given in the footnote of Table 3 are based on more comprehensive tests, they supersede those given in Technical Bulletin 158 (*8*).

TABLE 3.—*Average comparative properties of clear wood of virgin-growth redwood compared with a number of other species*

Commercial and botanical name of species	Trees tested	Specific gravity, oven-dry, based on volume when green	Weight per cubic foot		Shrinkage from green to oven-dry condition based on dimensions when green			Composite strength values				
			Green	At 12 per cent moisture content	Radial	Tangential	Volumetric (composite value)	Bending strength	Compressive strength (endwise)	Stiffness	Hardness	Shock resistance
												
1	2	3	4	5	6	7	8	9	10	11	12	13
	Number		*Pounds*	*Pounds*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Redwood [1] (Sequoia sempervirens)	16	0.39	52	28	100	100	100	100	100	100	100	100
Cedar, Port Orford (Chamaecyparis lawsoniana)	14	.40	36	29	192	172	158	99	87	123	89	122
Cedar, eastern red (Juniperus virginiana)	5	.44	37	33	129	118	116	81	84	58	150	175
Cedar, western red (Thuja plicata)	15	.31	27	23	100	125	113	72	72	79	70	80
Cedar, northern white (Thuja occidentalis)	5	.29	28	22	88	118	103	60	50	57	56	72
Cypress, southern (Taxodium distichum)	26	.42	50	32	158	155	155	95	89	99	96	117
Douglas fir (Pseudotsuga taxifolia) (Coast type)	34	.45	38	34	208	195	181	108	104	132	109	125
Douglas fir (Pseudotsuga taxifolia) (Rocky Mountain type)	10	.40	35	30	150	155	154	90	81	104	96	103
Fir, lowland white (Abies grandis)	10	.37	44	28	133	180	157	87	80	114	80	111
Fir, noble (Abies nobilis)	9	.35	30	26	188	208	188	89	74	109	72	105
Fir, silver (Abies amabilis)	6	.35	36	27	188	250	212	84	74	107	69	108
Fir, white (Abies concolor)	20	.35	47	26	133	175	142	87	71	93	78	92
Firs, white (Average of four species)	45	.35	41	26	158	198	164	87	74	103	76	102
Hemlock, western (Tsuga heterophylla)	18	.38	41	29	179	198	179	89	82	105	93	112
Pine, loblolly (Pinus taeda)	10	.50	54	38	229	188	190	112	101	121	115	143
Pine, longleaf (Pinus palustris)	34	.55	50	41	221	188	185	128	119	138	141	158
Pine, northern white (Pinus strobus)	18	.34	36	25	96	150	124	76	65	87	65	85
Pine, shortleaf (Pinus echinata)	12	.49	51	38	212	205	191	117	101	124	126	171
Pine, sugar (Pinus lambertiana)	9	.35	51	25	121	140	118	77	66	82	70	85
Pine, western white (Pinus monticola)	14	.36	35	27	171	185	176	83	73	100	65	100
Pine, ponderosa (Pinus ponderosa)	31	.38	45	28	162	158	145	78	67	82	76	89
Spruce, Sitka (Picea sitchensis)	25	.37	33	28	179	188	173	87	73	105	81	117

[1] Columns 6 to 13 are based on figures for comparative properties for redwood of 2.4, 4, 67, 83, 103, 137, 54, and 65, respectively, which, owing to the greater number of tests, supersede the comparative figures given in U. S. Department of Agriculture Technical Bulletin 158 (*8*).

TABLE 4.—*Average mechanical properties of redwood* [1]

[Based on tests of small [2] clear specimens in the green and air-dry condition [3]]

Common and botanical name	Trees tested	Rings per inch	Moisture content	Specific gravity, oven dry, based on—		Weight per cubic foot	Shrinkage from green to oven-dry condition, based on dimensions when green			Static bending					Impact bending			Compression parallel to grain		Compression perpendicular to grain—fiber stress at elastic limit	Shearing strength parallel to grain	Tension perpendicular to grain	Hardness	
				Volume when green or at 12 per cent moisture	Volume when oven dry		Volumetric	Radial	Tangential	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work in bending—		Fiber stress at elastic limit	Work in bending to elastic limit	Height of drop causing complete failure (50-pound hammer)	Fiber stress at elastic limit	Maximum crushing strength				Load required to embed a 0.444-inch ball to one-half its diameter	
													To elastic limit	To maximum load									End	Side
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Redwood (Sequoia sempervirens):	*Number*	*Number*	*Per cent*			*Lbs.*	*Per cent*	*Per cent*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*In.-lbs. per cu. in.*	*In.-lbs. per cu. in.*	*Lbs. per sq. in.*	*In.-lbs. per cu. in.*	*Ins.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs.*	*Lbs.*
Green	16	29	112	0.39	0.42	52	6.8	2.4	4.0	4,820	7,500	1,180	1.18	7.4	8,920	3.2	21	3,730	4,200	520	800	260	570	410
Seasoned			12	.40		28				6,980	10,100	1,350	2.07	6.9	10,250	3.6	19	4,740	6,200	870	940	240	800	480

[1] Comparable data on other species are presented in the U. S. Department of Agriculture Bulletin 556 (9).
[2] Test specimens 2 by 2 inches in section. Bending specimens 30 inches long; others shorter, depending on kind of test.
[3] Values for seasoned material are adjusted to an average air-dry condition of 12 per cent moisture content.

Table 4 presents values for redwood in a green and air-dry condition, based on tests of small, clear specimens (*1*). The values of Table 4 are comparable to the values for other species given in United States Department of Agriculture Bulletin 556 (*9*) and are used by engineers and architects for calculating the load-carrying capacity of wood, and in arriving at safe working stresses (*8*) for structural timbers containing defects.

RESULTS OF STRENGTH TESTS ON SECOND-GROWTH REDWOOD

There is comparatively little second-growth redwood, and from a commercial standpoint it is of practically no importance at the present time. The detailed strength values for second-growth have therefore been presented in the Appendix. The second-growth redwood used for the strength tests was classified according to whether it was from dense stands or from openly grown stands. The second-growth redwood from the dense stands was somewhat lower in weight and strength than the virgin-growth redwood, but, like virgin-growth redwood, had relatively high strength values for its weight.

Relatively few second-growth redwood trees from open stands are to be found. Those tested were lighter than either virgin-growth redwood or second-growth redwood from dense stands, and were also lower in some important strength properties than would be expected from their weight.

FACTORS AFFECTING THE PROPERTIES AND USES OF REDWOOD

Since second-growth redwood is not of commercial importance at the present time, the following discussion of properties and uses is concerned chiefly with virgin-growth redwood.

RELATION BETWEEN SPECIFIC GRAVITY AND STRENGTH

Strength studies on many species of wood have shown that there is a definite relation between the specific gravity of wood (oven dry) and its several strength properties (*10*). In general, the higher the weight of the dry wood, the greater is the strength. This relation of weight and strength holds among the different species of wood and also among individual boards of any one species.

Frequently a given species is characteristically high or low in different properties as compared with other species of the same specific gravity. It is rare that any species is, for its weight, exceptional in all of its strength properties.

The weight-strength relations for individual boards of any one species are often different from the weight-strength relations based on a number of different species. Curves illustrating the relationship between specific gravity and a number of strength properties of virgin-growth redwood in a green condition, based on values of individual tests, are shown in Figures 9 to 11. While there is a general relation between specific gravity and strength, there is still considerable deviation of individual values from the curve best representing the plotted points. In the curves illustrated, side hardness increases

most rapidly with an increase in specific gravity, maximum crushing strength next, and modulus of rupture least rapidly.[4]

It may be noted that when a property increases rapidly with specific gravity, as, for example, hardness, a small difference in specific gravity accounts for a relatively large difference in that property. Thus in redwood, if one board is twice as high as another in specific gravity, it would be expected to have not twice, but four

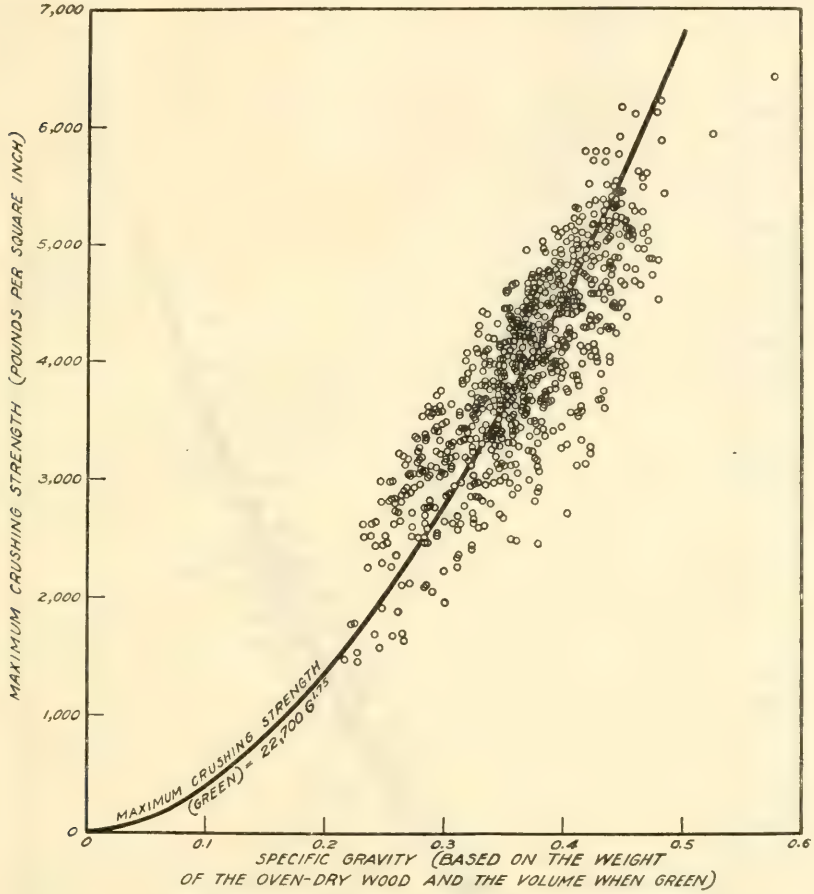


FIGURE 9.—Relation of maximum crushing strength of green virgin-growth redwood to specific gravity

times the hardness, as this property varies as the square of the specific gravity.

In bending strength, crushing strength, and hardness, the values for virgin-growth redwood are somewhat higher for the specific gravity than would be expected from the average behavior of other

[4] The equations for specific gravity-strength curves for green redwood are as follows: Side hardness = 2,780 G^2; maximum crushing strength = 22,700 $G^{1.75}$; and modulus of rupture = 31,100 $G^{1.5}$. Among different species the power of G for these properties has been found to be 2.25, 1.00, and 1.25, respectively; G in all cases representing the specific gravity, oven dry, based on volume when green.

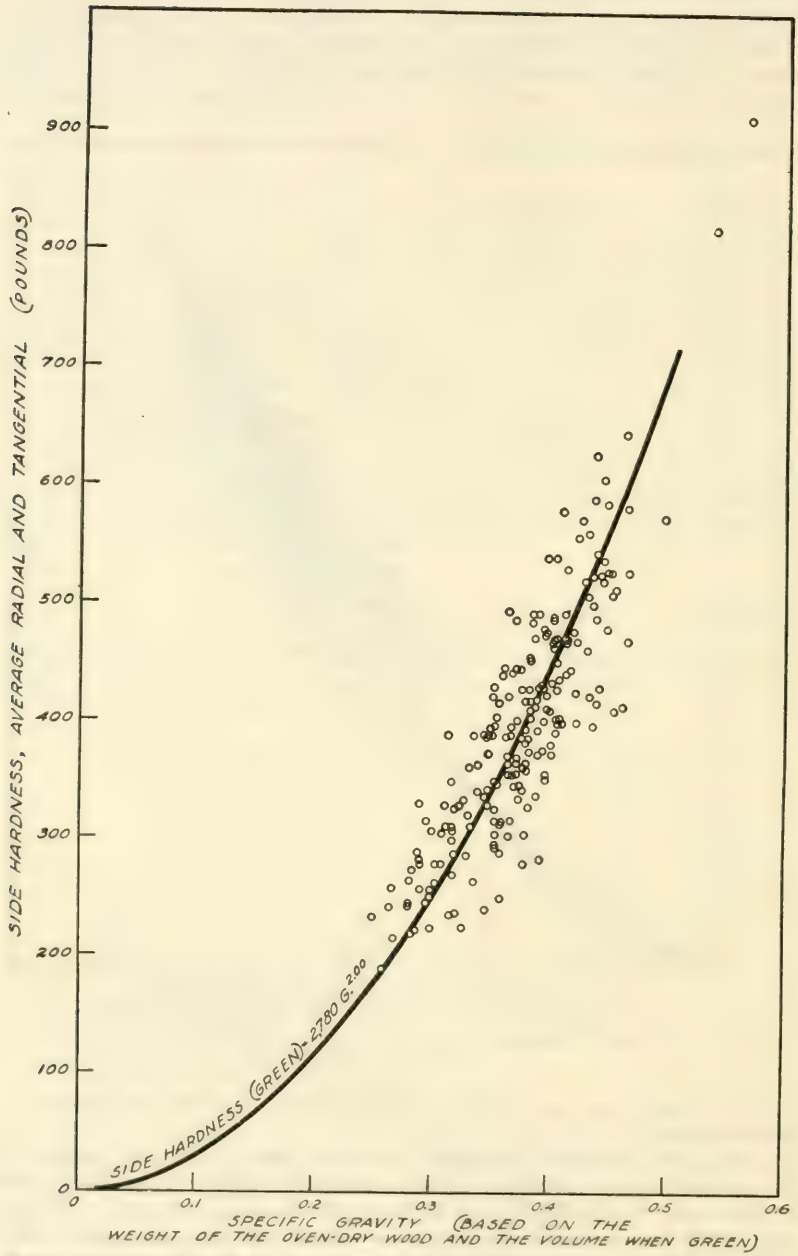


FIGURE 10.—Relation of side hardness of green virgin-growth redwood to specific gravity

FIGURE 11.—Relation of modulus of rupture of green virgin-growth redwood to specific gravity

species, while the values for shock resistance as measured by total work in static bending and height of drop in impact bending are somewhat lower. (P. 43.)

RELATION BETWEEN MOISTURE AND STRENGTH

Small, clear pieces of wood in drying from the green condition usually increase in most strength properties after reaching the fiber-saturation point. (P. 43.) The amount of the increase depends upon the extent of the drying, the property under consideration, and the species. Though redwood increases in many strength properties during seasoning, the increase is less than for most species. A few properties, particularly those indicative of shock resistance, as measured by total work in static bending and height of drop, show for redwood, as for numerous other species, an actual decrease due to seasoning.

STRENGTH AS RELATED TO HEIGHT IN TREE

In many species, the wood from near the ground is heavier and in some strength properties, particularly shock resistance, excels that from higher in the tree. However, this was not so in virgin-growth redwood as the butt cuts, although of slightly higher specific gravity than the next adjoining logs, were actually somewhat lower in many strength properties. The top logs were appreciably lighter and consistently lower in strength than the butt cuts or material directly above the butt. In other words, the strongest virgin-growth redwood, all properties considered, comes from just above the butt cuts. (P. 39.)

MOISTURE DISTRIBUTION WITHIN THE TREE

All living trees contain moisture, a considerable proportion of which must usually be removed from the lumber or other products by seasoning to condition it for service. The amount of moisture found in the tree varies greatly among different species, and often in different parts of the same tree (*6*). Figure 12 illustrates the average distribution of moisture for the heartwood and the sapwood throughout the height in tree, and is based on data from 43 virgin-growth redwood trees.

It is evident from Figure 12 that the sapwood is appreciably higher in moisture content than the heartwood, and tends to increase slightly in moisture with height in tree. The heartwood, on the other hand, decreases rapidly in moisture content (p. 45) from a value of about 150 per cent at the stump of an average individual tree to about 60 per cent at mid-height, and then maintains this condition fairly uniformly to the top of the merchantable length. At the base of the tree the moisture content of the heartwood increased appreciably from the pith outward, but at a height of 60 feet or more it became more uniform throughout the cross section.

Although Figure 12, which is based on averages, shows very uniform and consistent relations, individual trees may differ considerably from these values in the amount and distribution of moisture.

The relatively high moisture content of the heartwood, particularly in the butt cuts, necessitates the removal of large quantities of water

in seasoning. This, together with the fact that the moisture moves much more slowly from the heartwood than from the sapwood, accounts for the relatively slow drying of material from the butt logs. The difference in moisture content between the butt and upper cuts emphasizes the desirability of avoiding in commercial kiln drying the mixing of both classes of stock.

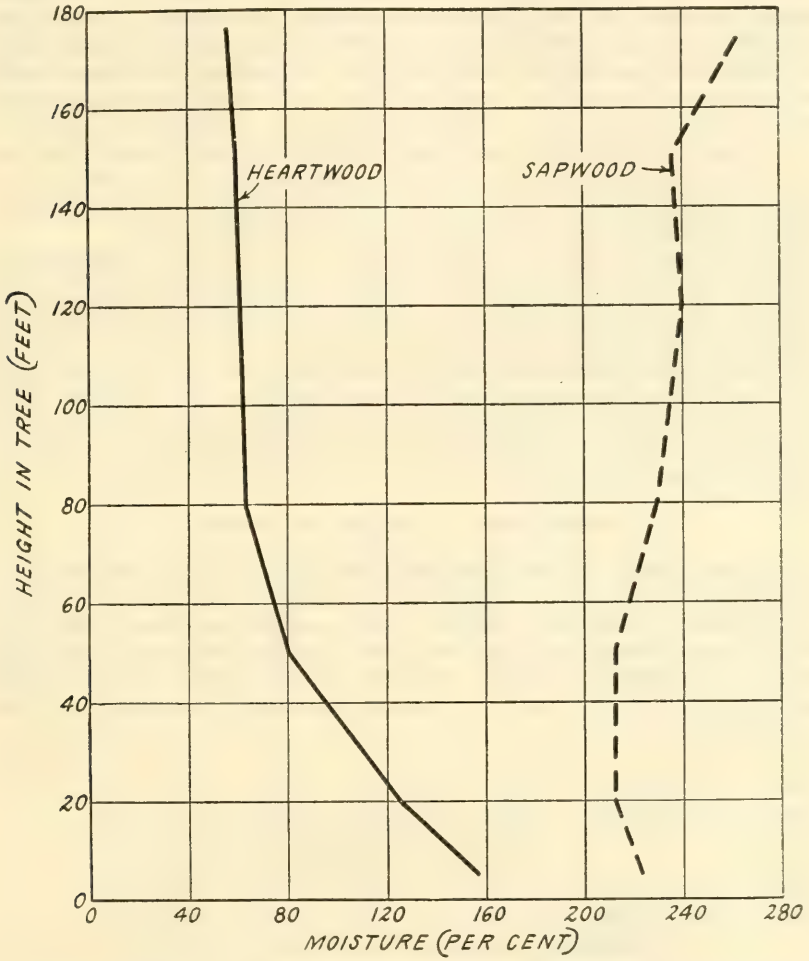


FIGURE 12.—Average distribution of moisture content of heartwood and sapwood in virgin-growth redwood trees relative to height

PROPERTIES AS AFFECTED BY EXTRACTIVES

The wood of many species contains considerable quantities of complex substances, such as resins, gums, oils, and other so-called extractives, many of which impart to the wood special characteristics or have an important commercial value. The amount of extractives frequently varies greatly within a single tree. In the virgin-growth redwood trees examined, the greatest range in the heartwood extrac-

tives within a single tree was from about 5 to 28 per cent, whereas the sapwood extractive content varied from about 4 to 8 per cent, based on the weight of the oven-dry wood. Second-growth redwood showed a smaller variation. In virgin-growth redwood the hot-water extractives averaged about 10 to 15 per cent for the heartwood, whereas in the sapwood the extractive content was only about 3 to 6 per cent. The extractives in the heartwood of redwood are reddish, which accounts for the distinctive color of the wood. Extractives affect the strength properties of redwood, the amount of the effect depending on the amount and distribution of extractives present, the moisture condition of the wood, and the particular strength property under consideration (*7*). Of the properties studied, the compressive strength parallel to the grain and the bending strength appear to be increased by the presence of extractives; the compressive strength to a greater extent. On the other hand, shock resistance under some conditions appears actually to be decreased.

Considering the effect of extractives, it seems very probable that they are largely responsible for certain strength properties of redwood being relatively high while others are lower than would be expected from the specific gravity of the wood; and for the somewhat lower than normal increase in strength with seasoning, although for more important properties the strength when dry is higher than the weight-strength relations would indicate. The relatively low shrinkage and high resistance to decay of redwood are also probably due to extractives.

RADIAL AND TANGENTIAL SHRINKAGE

For practically all uses, the characteristic shrinking and swelling of wood with moisture changes are undesirable, although the degree of shrinkage permissible differs greatly in different uses. The relatively low shrinkage of the heartwood across the grain commends redwood for uses where this property is important. Measurements on virgin-growth redwood gave values of average shrinkage as shown in Table 5.

TABLE 5.—*Shrinkage of virgin-growth redwood from the green to the oven-dry condition, in percentage, based on dimensions when green*

Shrinkage	Heartwood	Sapwood
Radial	2.4	3.2
Tangential	4.0	5.2
Volumetric	6.7	----

The shrinkage from the green condition to an air-dry condition of approximately 12 per cent moisture would be about one-half of that given.

The sapwood of both virgin-growth and second-growth redwood shrinks considerably more than the heartwood, but since virgin-growth redwood has only a narrow band of sapwood, most of which is removed in manufacture, the shrinkage of the heartwood is the more important. The radial and tangential shrinkage of the sap-

wood of virgin-growth redwood corresponds very closely with that to be expected from the specific gravity or weight, whereas the heartwood shrinks only about 65 per cent as much as would be expected from its specific gravity.

Since the heartwood and sapwood are from all appearances structurally the same, and the primary difference between heartwood and sapwood is extractives, it would seem that the extractives are the cause of the relatively low shrinkage of the heartwood. Certain sugars injected into wood will materially reduce the shrinkage, and it is possible that extractives in redwood act in a similar manner in reducing shrinkage.

COMPRESSION WOOD AND ENDWISE SHRINKAGE

Compression wood, which is found in redwood and other softwoods, is an abnormal growth frequently occurring on the underside of leaning trees and limbs of the various softwood (coniferous) species. It is denser and harder than the normal wood, is characterized by wide annual-growth rings, and includes what appears to be an excessive summer-wood growth. The contrast in color between spring wood and summer wood is usually less in compression wood than in normal wood. (Pl. 6.)

Of the 56 virgin-growth trees examined in the specific gravity survey (p. 3), 62 per cent contained some compression wood. However, out of a total of 4,046 specimens 2 by 2 inches square, cut from the 56 virgin trees, only 3.7 per cent contained compression wood; that is, when compression wood was present it usually made up but a very small proportion of the total volume of the trees.

The endwise, or longitudinal, shrinkage in the normal wood of practically all species including redwood is so small as to be relatively unimportant. Compression wood, however, has an endwise shrinkage so great as to materially affect its use. The maximum endwise shrinkage in compression wood in the redwood studied was 1.6 per cent from a green to an oven-dry condition, an equivalent of slightly over 3 inches in a 16-foot board if it were oven dried from a green condition (*5*).

That the bulk of redwood does not shrink excessively along the grain is shown in Table 6, in which are given, for both virgin-growth and second-growth, the percentage of the total number of specimens falling within narrow shrinkage classes. This table shows that out of 438 specimens of virgin-growth redwood, 85.8 per cent shrank less than 0.2 per cent along the grain in drying from the green to the oven-dry condition. In drying to an air-dry condition of about 12 per cent moisture content, only about one-half as much shrinkage would occur.

TABLE 6.—*Frequency distribution of longitudinal shrinkage of redwood*

Shrinkage class [1]	Virgin growth [2]		Second growth			
			Closely grown [3]		Openly grown [4]	
	In class	In class and below	In class	In class and below	In class	In class and below
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
0 to 0.04 per cent	3.8	3.8	20.2	20.2	4.3	4.3
0.05 to 0.09 per cent	25.6	29.4	7.1	27.3	18.1	22.4
0.10 to 0.14 per cent	40.4	69.8	26.5	53.8	12.9	35.3
0.15 to 0.19 per cent	16.0	85.8	10.7	64.5	20.7	56.0
0.20 to 0.24 per cent	4.5	90.3	19.1	83.6	14.6	70.6
0.25 to 0.29 per cent	3.2	93.5	2.2	85.8	6.0	76.6
0.30 to 0.34 per cent	1.6	95.1	4.1	89.9	5.3	81.9
0.35 to 0.39 per cent	1.4	96.5	1.9	91.8	6.0	87.9
0.40 to 0.44 per cent	.5	97.0	1.6	93.4	1.7	89.6
0.45 to 0.49 per cent	.9	97.9	1.4	94.8	2.6	92.3
0.50 to 0.54 per cent	.5	98.4	1.4	96.2	1.7	94.0
0.55 to 0.59 per cent	.7	99.1	1.6	97.8	1.7	95.7
0.60 to 0.64 per cent	.9	100.0	0.0	97.8	.9	96.6
0.65 to 0.69 per cent			.3	98.1	1.7	98.2
0.70 to 0.79 per cent			.6	98.7	.9	99.1
0.80 to 0.89 per cent			.8	99.5	.9	100.0
0.90 to 0.99 per cent			.5	100.0		

[1] The average shrinkage per specimen was 0.145 per cent for virgin growth, 0.165 for closely grown second growth, and 0.219 for openly grown second growth.
[2] Based on 438 specimens.
[3] Based on 366 specimens.
[4] Based on 116 specimens.

Where compression wood is present in the same board with normal wood, the unequal endwise shrinkage in the two parts causes bowing and crooking, which is usually a more serious disadvantage than direct shortening. Material containing pronounced compression wood is undesirable for practically all lumber uses and should be rejected.

COMPARISON OF THE STRENGTH OF COMPRESSION WOOD AND NORMAL REDWOOD

Strength tests were made both on normal redwood and on pronounced compression wood from the same trees. (Table 7.) Although the compression wood averaged about 35 per cent higher in specific gravity than the normal wood, it was actually lower in a number of strength properties, being decidedly lower in stiffness. In those properties in which it did excel normal wood it was in most cases but little better. Weight for weight, it was much inferior to normal wood in all properties studied.

TABLE 7.—*Ratio of strength of compression wood to normal wood for virgin-growth redwood*

Property	Ratio of compression wood to normal wood	
	Green	Air dry
	Per cent	*Per cent*
Specific gravity [1]	135	133
Static bending:		
Modulus of rupture	102	87
Modulus of elasticity	62	63
Work to maximum load	92	108
Compression parallel to grain: Maximum crushing strength	117	101
Toughness	84	100

[1] Based on the weight of the oven-dry wood and volume when green

SUMMARY

The redwood studied was higher in such properties as bending strength, crushing strength, and hardness than would be expected from its specific gravity, while in shock resistance it was usually somewhat lower.

Redwood in the form of small specimens increased in strength in drying, although the relative increase was less than for most species. A few properties, particularly those indicative of shock-resisting ability frequently showed a decrease due to drying.

The virgin-growth redwood from Mendocino County was somewhat stronger than that from Humboldt County, but the differences in most strength properties were not so great as would be expected from the differences in weight.

The strongest virgin-growth redwood, all properties considered, came from just above the butt log.

The moisture in the heartwood of the virgin-growth redwood studied varied from an average of about 140 to 175 per cent at the stump of individual trees, to about 60 per cent at mid height, beyond which point it remained almost uniform throughout the rest of the tree. The moisture in the sapwood averaged over 200 per cent throughout the entire height of the tree.

The extractives in the wood affected the strength of the redwood studied, increasing such properties as bending strength and compressive strength, while shock resistance under some conditions was actually decreased.

The shrinkage across the grain of the heartwood of the redwood studied was relatively low. The low shrinkage appeared to be due primarily to the extractives in the heartwood, as the sapwood, which had a lower extractive content, was considerably higher in shrinkage.

Occasional pieces of redwood, like those of other softwood species, contained compression wood in varying degrees. Compression wood has a much higher endwise shrinkage than normal wood and is also deficient in strength for its weight and therefore boards containing much of it should be discarded for most lumber uses.

APPENDIX

DETAILED DATA FROM THE SPECIFIC GRAVITY SURVEY

COLLECTION OF SAMPLES

The samples collected in the specific gravity survey consisted of whole or partial cross sections taken at different heights from each of 27 virgin-growth and 24 second-growth trees from Mendocino County and from 29 virgin-growth and 18 second-growth trees from Humboldt County, Calif. From these sections, approximately 4,000 specific gravity specimens were taken for the virgin-growth material and 1,500 for the second-growth. The second-growth trees consisted of 31 closely grown and 11 openly grown trees.

METHOD

Partial sections including the pith and a little more than half the cross section of the log were obtained from the virgin-growth trees. (Fig. 13.) These sections were approximately 6 inches in length (along the grain), and were sawed out at average heights of 4, 23, 60, 104, 148, and 188 feet above the ground. (Fig. 14.) Specific gravity specimens approximately 2 by 2 by 6

inches in size were cut from these partial sections from bark to bark, along a diametrical line. The specific gravity determinations, based on green volume and oven-dry weight, were made at temporary field headquarters. The specimens were then sent to the Forest Products Laboratory where specific gravity determinations, based on oven-dry volume and weight, were made.

The sections from the second-growth redwood trees comprised the entire cross section of the log and were taken at heights of approximately 2, 14, 37, and 62 feet above the ground. Specific gravity specimens about 2 by 2 by 6 inches in size were taken through the pith from bark to bark.

The second-growth redwood sections were sent to the Forest Products Laboratory to have their specific gravity determined. The sections from the second-growth trees were cut 1 to 1½ feet in length to make it possible, despite some loss of moisture from the ends during transit, to obtain green material for the specific gravity tests.

The specific gravity determinations were made by the immersion method (*1*). Volumetric-shrinkage measurements from the green to the oven-dry condition were also obtained as a part of this procedure.

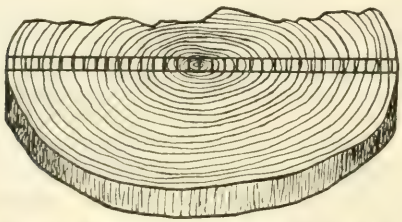


FIGURE 13.—Diagram showing method of taking specific gravity specimens from bark to bark across tree sections

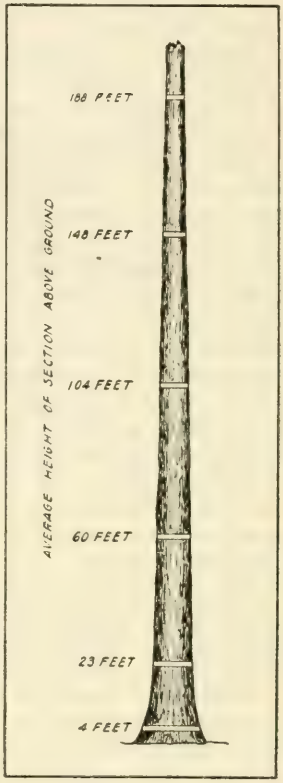


FIGURE 14.—Diagram showing position of sections taken at various tree heights

RESULTS

Table 8 gives values of the probable variation in the specific gravity of virgin-growth redwood in individual specimens by trees, sites, lots, and counties and in individual trees with similar grouping. Table 8 also shows the effect on specific gravity and its variation when pieces containing compression wood are rejected. In addition, it permits a comparison of redwood from the whole tree with that from the second log.

TABLE 8.—*Probable variation values of the specific gravity of virgin-growth and second-growth redwood*

VIRGIN GROWTH

Place of growth		Lot number	Site class or stocking	Tree identification number	All bolts							Second section						Trees	Specific gravity [1]	Probable variation [2] of an individual tree from corresponding average
					Specimens containing compression wood	All specimens			Without compression wood			All specimens			Without compression wood					
County	Land description					Specimens	Specific gravity [1]	Probable variation [2] of individual specimen from corresponding average	Specimens	Specific gravity [1]	Probable variation [2] of individual specimen from corresponding average	Specimens	Specific gravity [1]	Probable variation [2] of individual specimen from corresponding average	Specimens	Specific gravity [1]	Probable variation [2] of individual specimen from corresponding average			
					Number	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*
Mendocino	T. 17 N., R. 16 W.	1	IV	15	3	64	0.377	10.58												
				16	2	71	.369	9.35												
				17	1	26	.379	4.54												
				18	6	48	.381	9.51												
				19	0	25	.364	9.95												
				Total or average		234	.374	9.86	222	0.370	8.90	59	0.384	7.06	55	0.379	6.07	5	0.374	1.51
		1	III	20	5	114	.337	11.77												
				21	2	82	.395	8.99												
				22	8	77	.391	8.80												
				23	4	31	.437	8.04												
				24	0	53	.409	7.67												
				Total or average		357	.380	11.17	338	.377	10.88	91	.396	9.63	83	.390	9.46	5	.394	7.20
		Total or average lot 1				591	.379	10.59				150	.391	8.82	138	.386	8.41	10	.384	5.02

[1] Specific gravity based on green volume and oven-dry weight.

[2] These percentage values are obtained by dividing the actual probable variation by the corresponding average specific gravity. For example, tree No. 1 (second growth) has an actual probable variation in specific gravity of 0.0292, an average specific gravity of 0.362, and the percentage probable variation is 0.0292 divided by 0.362 times 100 or 8.07 per cent.

TABLE 8.—*Probable variation values of the specific gravity of virgin-growth and second-growth redwood*—Continued

VIRGIN GROWTH—continued

Place of growth					All bolts							Second section								
						All specimens			Without compression wood			All specimens			Without compression wood					
County	Land description	Lot number	Site class or stocking	Tree identification number	Specimens containing compression wood	Specimens	Specific gravity	Probable variation of individual specimen from corresponding average	Specimens	Specific gravity	Probable variation of individual specimen from corresponding average	Specimens	Specific gravity	Probable variation of individual specimen from corresponding average	Specimens	Specific gravity	Probable variation of individual specimen from corresponding average	Trees	Specific gravity	Probable variation of an individual tree from corresponding average
					Number	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*
		2	II	25	0	95	.389	8.07												
				26	12	64	.387	10.25												
				27	5	110	.385	9.96												
				28	0	96	.366	9.40												
				29	1	102	.409	7.30												
				Total or average		467	.388	9.20	449	.383	8.83	114	.408	8.77	110	.406	8.40	5	.387	2.95
		2	II	30	0	72	.347	10.75												
				31	1	102	.426	8.06												
				Total or average		174	.393	11.21	173	.392	11.31	45	.408	10.48	44	.407	10.54	2	------	------
Mendocino	T. 19 N., R. 16 W.	2	IV	32	2	55	.406	8.31												
				33	1	44	.396	8.68												
				34	4	45	.438	8.85												
				35	2	60	.412	12.74												
				36	0	71	.419	11.82												
				Total or average		275	.415	10.79	266	.412	10.54	80	.416	8.28	79	.415	8.17	5	.414	2.97

			37	5	62	.381	10.95													
			38	1	52	.359	7.33													
			39	1	86	.364	9.76													
	2	III	40	2	60	.381	8.63													
			41	2	42	.387	7.89													
			Total or average		302	.373	9.82	291	.370	9.32	79	.388	8.22	77	.387	7.98	5	.374	4.33	
	Total or average lot 2				1,218	.391	10.20				318	.406	8.97	310	.404	8.75	17	.391	4.41	
	Total or average lots 1 and 2				1,809	.387	10.36				468	.401	9.01				27	.388	4.48	
			1	6	81	0.368	7.54													
			2	0	66	.359	8.66													
	3	II	3	0	56	.413	6.55													
			14	0	109	.340	4.68													
			Total or average		312	.364	8.21	306	0.363	8.09	77	0.372	7.85	76	0.371	7.68	4	0.370	6.90	
			4	1	25	.399	11.57													
			5	6	84	.365	9.10													
	3	III	6	0	18	.386	8.90													
			7	3	41	.373	6.56													
			Total or average		168	.375	9.34	158	.373	9.16	36	.398	9.12	32	.396	9.50	4	.381	3.22	
			8	16	99	.399	11.65													
			9	0	46	.337	8.61													
			10	0	104	.380	7.93													
Humboldt---- T. 1 S., R. 2 E	3	III	11	0	83	.405	8.89													
			12	0	103	.377	11.43													
			47	0	132	.300	6.90													
			Total or average		567	.364	12.15	551	.360	11.40	123	.385	11.65	113	.374	10.34	6	.366	8.30	
			48	0	74	.355	7.45													
			49	0	100	.360	8.45													
			50	0	56	.431	7.02													
	3	I	51	1	104	.383	6.31													
			52	0	118	.327	8.66													
			Total or average		452	.365	9.69	452	.365	9.69	91	.377	9.21	91	.377	9.21	5	.371	8.16	
			53	4	80	.387	8.96													
			54	1	89	.333	10.17													
			55	0	84	.299	7.90													
	3	III	56	2	55	.363	5.98													
			57	17	91	.401	11.62													
			Total or average		399	.356	11.94	375	.349	10.00	92	.364	11.71	87	.358	10.98	5	.357	9.00	

TABLE 8.—*Probable variation values of the specific gravity of virgin-growth and second-growth redwood*—Continued

VIRGIN GROWTH—continued

Place of growth		Lot number	Site class or stocking	Tree identification number	All bolts							Second section						Trees	Specific gravity	Probable variation of an individual tree from corresponding average
					Specimens containing compression wood	All specimens			Without compression wood			All specimens			Without compression wood					
County	Land description					Specimens	Specific gravity	Probable variation of individual specimen from corresponding average	Specimens	Specific gravity	Probable variation of individual specimen from corresponding average	Specimens	Specific gravity	Probable variation of individual specimen from corresponding average	Specimens	Specific gravity	Probable variation of individual specimen from corresponding average			
					Number	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*
		3	IV	58	0	71	.349	8.41												
				59	7	45	.371	8.58												
				60	1	64	.352	8.72												
				61	11	99	.334	10.36												
				62	4	60	.400	7.25												
				Total or average		339	.357	9.73	316	.352	8.90	91	.354	9.01	87	.350	8.52	5	.361	5.47
		Total or average lot 3				2,237	.363	10.60				510	.373	10.40	486	.368	9.78	29	.367	5.99
Mendocino and Humboldt.		Grand total or average lots 1, 2, and 3				4,046	.374	10.67				978	.386	9.92	934	.383	9.62	56	.377	5.54

Mendocino	T. 17 N., R. 16 and 17 W.	4	III	1	0	22	0.362	8.07													
				2	0	22	.353	5.31													
				3	0	14	.369	7.99													
				4	0	30	.323	9.17													
				5	0	18	.375	10.17													
				Total or average		106	.352	9.18	106	0.352	9.18	28	0.335	5.98	28	0.335	5.98	5	0.356	4.46
		4	III	6	4	26	.358	10.84													
				7	4	28	.356	7.22													
				8	0	22	.363	8.05													
				9	0	13	.367	7.40													
				Total or average		89	.360	8.67	81	.354	7.70	26	.339	6.63	24	.333	5.59	4	.361	1.12
		4	II	10	0	28	.325	4.74													
				11	0	15	.343	3.10													
				12	10	27	.459	4.68													
				13	0	24	.327	5.08													
				14	0	32	.335	6.60													
				24	0	27	.375	5.15													
				10, 11, 13, 14, 24		126	.341	6.54	126	.341	6.54	35	.328	5.26	35	.328	5.26	5	.341	4.63
				Total or average		153	.362	13.78	143	.353	9.15	42	.349	10.21	40	.341	8.61			
		4	IV	17	0	18	.383	7.24													
				18	1	26	.368	5.83													
				19	0	16	.377	8.34													
				Total or average		60	.375	7.15	59	.373	6.97	20	.354	3.32	20	.354	3.32	3	.376	1.92
		4	II	20	0	22	.380	5.43													
				21	2	24	.379	5.96													
				22	0	24	.348	7.94													
				23	3	21	.349	9.52													
				Total or average		91	.364	7.81	86	.359	7.22	24	.349	6.83	24	.349	6.83	4	.364	4.06
		4	Closely grown.	1-11, 13, 14, 17-24		472	.356	8.20				133	.339	6.03				21	.358	3.63
		4	Openly grown.	25	0	20	.365	6.60	20	.365	6.60	6	.346	4.90	6	.346	4.90			
				26	0	27	.306	6.12													
				27	0	22	.288	7.05													
				26 and 27		49	.298	6.88	49	.298	6.88	18	.277	4.32	18	.277	4.32			
				Total or average		69	.317	9.31	69	.317	9.31	24	.294	7.95	24	.294	7.95	3	.320	12.02

TABLE 8.—*Probable variation values of the specific gravity of virgin-growth and second-growth redwood*—Continued

SECOND GROWTH—continued

Place of growth					All bolts							Second section								
						All specimens			Without compression wood			All specimens			Without compression wood					
County	Land description	Lot number	Site class or stocking	Tree identification number	Specimens containing compression wood	Specimens	Specific gravity	Probable variation of individual specimen from corresponding average	Specimens	Specific gravity	Probable variation of individual specimen from corresponding average	Specimens	Specific gravity	Probable variation of individual specimen from corresponding average	Specimens	Specific gravity	Probable variation of individual specimen from corresponding average	Trees	Specific gravity	Probable variation of an individual tree from corresponding average
					Number	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*	*Number*		*Per cent*
		5	III	29	0	28	.315	7.13												
				30	0	24	.381	7.08												
				35	0	22	.319	6.22												
				36	0	24	.346	8.42												
				37	1	28	.344	7.25												
				Total or average		126	.341	8.61	125	.340	8.59	34	.322	4.44	34	.322	4.44	5	.341	6.03
		5	III	31	4	22	.397	4.86												
				32	0	25	.351	4.84												
				33	0	21	.351	4.94												
				34	1	26	.377	6.58												
				48	0	25	.374	7.31												
				Total or average		122	.370	6.62	117	.368	6.53	35	.369	5.08	35	.369	5.08	5	.370	4.10
		5	Closely grown.	Total or average		248	.355	8.13				69	.346	6.71				10	.356	5.36
Humboldt	T. 5 N., R. 1 E.																			

				38	0	29	.327	4.45											
				39	0	27	.335	5.97											
				Total or average	56	.331	5.39	56	.331	5.39	20	.316	4.52	20	.316	4.52	2		
				40	0	29	.301	8.17											
				41	0	22	.333	7.26											
		5	Openly grown.	42	1	20	.331	6.88											
				Total or average	71	.319	8.27	70	318	8.15	25	.304	7.75	24	.300	6.89	3	.322	5.29
				44	0	39	.294	6.22											
				45	0	17	.330	7.33											
				46	0	15	.311	5.65											
				Total or average	71	.306	7.30	71	.306	7.30	25	.289	4.46	25	.289	4.46	3	.312	5.50
				Total or average	198	.318	7.45				70	.302	6.46				8	.320	3.63
Mendocino and Humboldt.		4 and 5.	do		267	.318	7.98				94	.300	6.87				11	.320	4.98
			Closely grown.		720	.356	8.17				202	.342	6.31				31	.357	4.10

The figures for probable variation are expressed in percentages of the corresponding average specific gravities to simplify comparisons. In calculating the probable variation of an individual specimen from the average, the usual formula was used, which assumes a normal distribution, as follows:

$$\text{Probable variation} = 0.6745\sqrt{\frac{\Sigma v^2}{n}}$$

Where r=residual between average specific gravity and each observed value
n=total number of specimens.

In calculating the probable variation of an individual tree from the average of the different tree groupings, correction was made for size of sample by multiplying the probable variation by $\sqrt{\frac{n}{n-2}}$, where n equals number of samples (*12*).

DETAILED DATA ON STRENGTH AND ASSOCIATED PROPERTIES OF REDWOOD

SELECTION OF TREES FOR STRENGTH TESTS

Specific gravity determinations were made in the field on about three times the number of trees required for the strength tests. The specific gravity determinations for each tree were confined to specimens from a section taken about 20 feet above the ground. The specimens were cut consecutively from bark to bark through the pith. This method gave results regarded as representative of the tree, and only those trees which best represented the range and average specific gravity of the species, as determined by the specific gravity survey (p. 3), were selected for the strength tests.

All logs chosen were from freshly cut trees and had the bark intact. It is common practice in the redwoods to peel the logs and then burn over the logged area or else first burn and then peel. Either method results in a large reduction of moisture in the logs, and the logs no longer remain representative of green stock. As green material is essential for the strength tests, the logs for this purpose could not be selected at the time of the usual logging operations but were cut and transported from the woods in advance of the main cut. A full and complete description of the trees and sites was also desired, and it was possible to obtain this only by working ahead of the regular logging operations.

The selection of second-growth trees was based on specific gravity determinations made on increment borings obtained in the usual manner. As second-growth redwood is not now being cut commercially, the increment-boring method eliminated the necessity of cutting and sampling more second-growth than would actually be used for test purposes.

STRENGTH OF REDWOOD

Table 9 presents actual test results for virgin-growth and second-growth redwood, together with a percentage figure representing the relation of these actual results to the value which would be expected for the species on the basis of the specific gravity-strength equation for the corresponding property. The equation value was obtained by substituting the specific gravity of redwood in the previously established general formulas expressing the relation of specific gravity to strength as determined by tests on 166 species (*8*). The percentage figures given are useful in considering the degree to which redwood differs, weight for weight, from the general average trend of other species.

Table 10 gives data on the mechanical properties of virgin-growth redwood by counties; Table 11 data on the mechanical properties of virgin-growth redwood as related to height in tree.

TABLE 9.—*Test-strength values of green and air-dried virgin-growth[1] and second-growth[2] redwood, and ratios of test values to values normally expected by specific gravity as indicated by tests of other species*

Description and property	Unit	Green						Air-dried					
		Virgin growth		Second growth				Virgin growth		Second growth			
				Closely grown		Openly grown				Closely grown		Openly grown	
		Description and test values	Ratio[3]	Description and test values	Ratio[3]	Description and test values	Ratio[3]	Description and test values	Ratio[3]	Description and test values	Ratio[3]	Description and test values	Ratio[3]
Lot No.		6, 7, and 8		7 and 8		7 and 8		6, 7, and 8		7 and 8		7 and 8	
Number:													
Trees		16		8		6		16		8		6	
Rings per inch		29		7		3		29		7		3	
Specific gravity:													
Volume as tested[4]		0.39		0.33		0.29		0.40		0.35		0.31	
Oven-dry volume		0.416		0.361		0.310							
Shrinkage:													
In volume	Per cent of dimensions when green	6.7		7.4		6.3							
Radial—sapwood	do	[5] 3.2		2.9		2.6							
Radial—heartwood	do	2.4		2.1		1.6							
Tangential—sapwood	do	[5] 5.2		5.9		5.0							
Tangential—heartwood	do	4.0		4.5		4.0							
Moisture content	Per cent	112		112		146		12.0		12.0		12.0	
Static bending:													
Specific gravity		0.388		0.331		0.297		0.405		0.350		0.308	
Fiber stress at elastic limit	Pounds per square inch	4,820	1.53	3,560	1.40	2,750	1.26	6,980	1.32	5,470	1.22	4,290	1.15
Modulus of rupture	do	7,500	1.38	6,060	1.38	4,600	1.22	10,100	1.24	8,310	1.20	6,460	1.12
Modulus of elasticity	1,000 pounds per square inch	1,176	1.28	1,002	1.29	642	.94	1,350	1.20	1,124	1.15	762	.88
Work to elastic limit	Inch-pounds per cubic inch	1.18	1.97	0.73	1.55	0.68	1.74	2.07	1.49	1.50	1.29	1.37	1.46
Work to maximum load	do	7.4	1.07	6.1	1.22	5.1	1.24	6.9	1.07	5.7	1.11	4.7	1.15
Work total	do	14.1	.90	10.3	.92	6.4	.74	8.6	.74	6.8	.76		
Impact bending (50-pound hammer):													
Specific gravity		0.393		0.334		0.292		0.408		0.347		0.301	
Fiber stress at elastic limit	Pounds per square inch	8,920	1.22	7,230	1.22	5,860	1.16	10,250	1.04	9,080	1.08	6,830	.98
Modulus of elasticity	1,000 pounds per square inch	1,410	1.23	1,188	1.22	848	1.00	1,660	1.23	1,478	1.25	1,012	.97
Work to elastic limit	Inch-pounds per cubic inch	3.2	1.23	2.5	1.25	2.3	1.36	3.6	.90	3.2	.97	2.7	1.00
Drop causing complete failure	Inches	20.9	.94	17.8	1.11	14.1	1.08	18.8	.99	15.6	1.04	10.9	.92

[1] The test values on virgin-growth redwood are for material from 20 to 32 feet above the ground.
[2] The test values on second-growth redwood are for material from 8 to 16 feet above the ground.
[3] Ratio of test values to values normally expected of a species of corresponding specific gravity as determined by equations based on tests of 166 species (8).
[4] Average of static bending, impact bending, compression perpendicular to grain, and hardness tests.

TABLE 9.—*Test-strength values of green and air-dried virgin-growth and second-growth redwood, etc.*—Continued

Description and property	Unit	Green						Air-dried					
		Virgin growth		Second growth				Virgin growth		Second growth			
				Closely grown		Openly grown				Closely grown		Openly grown	
		Description and test values	Ratio	Description and test values	Ratio	Description and test values	Ratio	Description and test values	Ratio	Description and test values	Ratio	Description and test values	Ratio
Compression parallel to grain:													
Specific gravity		0.380		0.318		0.282		0.402		0.344		0.303	
Crushing strength at elastic limit	Pounds per square inch	[5] 3,730	1.82	2,820	1.63	1,820	1.20	[5] 4,740	1.35	3,820	1.25	2,690	.99
Maximum crushing strength	do	4,200	1.60	3,280	1.48	2,320	1.19	6,200	1.27	5,270	1.23	3,860	1.02
Modulus of elasticity	1,000 pounds per square inch	[5] 1,488	1.31	1,212	1.26	774	.92	[5] 1,550	1.15	1,260	1.07	820	.78
Compression perpendicular to grain:													
Specific gravity		0.385		0.329		0.293		0.402		0.351		0.310	
Fiber stress at elastic limit	Pounds per square inch	524	1.46	348	1.46	314	1.66	868	1.49	653	1.51	561	1.71
Shearing strength:													
Radial	do	788	1.04	703	1.14	581	1.10	957	.96	933	1.10	788	1.11
Tangential	do	818	1.01	750	1.14	703	1.25	933	.87	939	1.02	951	1.25
Average	do	803	1.02	726	1.14	642	1.18	945	.91	936	1.06	870	1.18
Tension perpendicular to grain:													
Radial	do	273	1.00	270	1.38	215	1.42	232	.78	218	.96	161	.90
Tangential	do	238	.67	311	1.23	314	1.62	240	.66	337	1.21	327	1.50
Average	do	256	.82	290	1.30	264	1.53	236	.72	278	1.10	244	1.23
Hardness: [6]													
Specific gravity		0.378		0.324		0.292		0.404		0.347		0.305	
End	Pounds	569	1.27	469	1.58	388	1.64	800	1.32	720	1.61	594	1.75
Radial	do	404	1.00	341	1.27	270	1.27	490	1.05	383	1.10	311	1.18
Tangential	do	423	1.02	360	1.31	299	1.37	470	.98	426	1.20	369	1.37
Average radial and tangential	do	414	1.01	350	1.29	284	1.32	480	1.01	404	1.15	340	1.28
Cleavage:													
Radial	Pounds per inch of width	177	1.08	172	1.46	142	1.56	143	.79	134	.96	118	1.08
Tangential	do	159	.83	183	1.34	169	1.59	153	.75	175	1.11	192	1.56
Average	do	168	.94	178	1.39	156	1.59	148	.76	154	1.04	155	1.34
Tension parallel to grain:													
Specific gravity				0.307		0.290							
Maximum tensile strength	Pounds per square inch	9,450		7,290		4,420		10,080		10,320		6,590	
Toughness: [7]													
Specific gravity		[5] 0.389		0.340		0.294		[5] 0.394		0.345		0.302	
Radial	Inch-pounds per specimen	[5] 57.6		62.8		46.7		[5] 49.6		45.7		29.6	
Tangential	do	[5] 105.5		94.5		55.1		[5] 76.0		63.3		34.6	
Average	do	81.6		78.6		50.9		62.8		54.5		32.1	

[5] Lots 7 and 8 only.
[6] Load required to embed a 0.444-inch ball to one-half its diameter.
[7] Specimens ⅝ by ⅝ by 10 inches, tested over an 8-inch span with load applied on tangential face nearest the pith.

TABLE 10.—*Average mechanical properties of virgin-growth redwood*[1] *as related to locality of growth*

Description and property	Unit	Green			Air-dried		
		Mendocino County	Humboldt County	Ratio Mendocino to Humboldt County	Mendocino County	Humboldt County	Ratio Mendocino to Humboldt County
Lot No.		6 and 7	8		6 and 7	8	
Trees	Number	9	7		9	7	
Rings per inch	do	33	25	1.32	32	25	1.28
Specific gravity:							
Volume as tested [2]		0.40	0.370	1.08	0.42	0.39	1.08
Oven-dry volume		0.422	0.411	1.03			
Shrinkage:							
In volume	Per cent of dimensions when green	6.7	6.8	.99			
Radial—sapwood	do	[3] 3.3	3.1	1.06			
Radial—heartwood	do	[3] 2.3	2.3	1.00			
Tangential—sapwood	do	[3] 4.8	5.6	.86			
Tangential—heartwood	do	[3] 3.7	4.1	.90			
Moisture content	Per cent	104	120		12	12	
Static bending:							
Specific gravity		0.405	0.370	1.09	0.418	0.392	1.07
Fiber stress at elastic limit	Pounds per square inch	5,030	4,620	1.09	7,300	6,640	1.10
Modulus of rupture	do	7,640	7,350	1.04	10,450	9,680	1.08
Modulus of elasticity	1,000 pounds per square inch	1,178	1,175	1.00	1,360	1,330	1.02
Work to elastic limit	Inch-pounds per cubic inch	1.33	1.04	1.28	2.24	1.84	1.22
Work to maximum load	do	7.5	7.4	1.01	7.5	6.4	1.17
Work, total	do	14.5	13.7	1.06	9.0	8.3	1.08
Impact bending (50-pound hammer):							
Specific gravity		0.407	0.379	1.07	0.427	0.388	1.10
Fiber stress at elastic limit	Pounds per square inch	9,310	8,520	1.09	10,600	9,840	1.08
Modulus of elasticity	1,000 pounds per square inch	1,431	1,389	1.03	1,700	1,625	1.05
Work to elastic limit	Inch-pounds per cubic inch	3.4	3.0	1.13	3.9	3.4	1.15
Drop causing complete failure	Inches	21.8	20.0	1.09	19.3	18.3	1.05
Compression parallel to grain:							
Specific gravity		0.398	0.361	1.10	0.419	0.386	1.09
Crushing strength at elastic limit	Pounds per square inch	[3] 3,880	3,580	1.08	[3] 4,860	4,620	1.05
Maximum crushing strength	do	4,290	4,110	1.04	6,490	5,960	1.09
Modulus of elasticity	1,000 pounds per square inch	[3] 1,550	1,425	1.09	[3] 1,630	1,476	1.10
Compression perpendicular to grain:							
Specific gravity		0.395	0.375	1.05	0.415	0.389	1.07
Fiber stress at elastic limit	Pounds per square inch	524	523	1.00	930	813	1.14

[1] Test values are for material from 20 to 32 feet above ground.
[2] Average of static bending, impact bending, compression perpendicular to grain, and hardness tests.
[3] Lot 7 only.

TABLE 10.—*Average mechanical properties of virgin-growth redwood as related to locality of growth*—Continued

Description and property	Unit	Green			Air-dried		
		Mendocino County	Humboldt County	Ratio Mendocino to Humboldt County	Mendocino County	Humboldt County	Ratio Mendocino to Humboldt County
Shearing strength:							
Radial	do	775	802	.97	1,000	909	1.10
Tangential	do	820	816	1.00	985	883	1.11
Average	do	798	809	.99	992	896	1.11
Tension perpendicular to grain:							
Radial	do	267	279	.96	248	218	1.14
Tangential	do	229	248	.92	245	234	1.05
Average	do	248	264	.94	246	226	1.09
Hardness [4]							
Specific gravity		0.399	0.357	1.12	0.415	0.393	1.06
End	Pounds	569	569	1.00	846	757	1.12
Radial	do	416	392	1.06	508	471	1.08
Tangential	do	428	418	1.02	477	461	1.03
Average radial and tangential	do	422	405	1.04	492	466	1.06
Cleavage:							
Radial	Pounds per inch of width	170	184	.92	153	130	1.18
Tangential	do	144	174	.83	158	146	1.08
Average	do	157	179	.88	156	138	1.13
Tension parallel to grain:							
Maximum tensile strength	Pounds per square inch	9,800	9,100	1.08	10,500	9,650	1.09
Toughness [5]							
Specific gravity		[3] 0.394	0.384	1.03	[3] 0.403	0.386	1.04
Radial	Inch-pounds per specimen	[3] 57.4	57.7	.99	[3] 50.6	48.9	1.03
Tangential	do	[3] 118.4	92.6	1.28	[3] 76.2	75.3	1.01
Average	do	[3] 87.9	75.2	1.17	[3] 63.4	62.1	1.02

[3] Lot 7 only.
[4] Load required to embed a 0.444-inch ball to one-half its diameter.
[5] Specimens $\frac{1}{16}$ by $\frac{1}{16}$ by 10 inches, tested over an 8-inch span with load applied on tangential face nearest the pith.

TABLE 11.—*Average mechanical properties of virgin-growth redwood as related to height in tree*

Description and property	Unit	Comparison of butt and second logs [1]						Comparison of top and second logs [1]					
		Green			Air-dried			Green			Air-dried		
		Butt logs	Second logs	Ratio butt to second logs	Butt logs	Second logs	Ratio butt to second logs	Top logs	Second logs	Ratio top to second logs	Top logs	Second logs	Ratio top to second logs
Lot Nos.		7 and 8	7 and 8		7 and 8	7 and 8		7 and 8	7 and 8		7 and 8	7 and 8	
Trees	Number	5	5		5	5		10	10		10	10	
Rings per inch	do	28	29	0.97	27	28	0.96	33	32	1.03	34	31	1.10
Moisture content	Per cent	158	120	1.32	12.0	12.0		66	110	.60	12	12	
Static bending:													
Specific gravity		0.392	0.392	1.00	0.417	0.409	1.02	0.350	0.380	.92	0.361	0.394	.92
Fiber stress at elastic limit	Pounds per square inch	4,520	4,630	.98	6,480	6,630	.98	3,920	4,430	.89	5,810	6,470	.90
Modulus of rupture	do	7,120	7,550	.94	9,410	10,100	.93	6,270	7,180	.87	8,530	9,660	.88
Modulus of elasticity	1,000 pounds per square inch	1,090	1,248	.87	1,266	1,400	.90	958	1,164	.82	1,110	1,323	.84
Work to elastic limit	Inch-pounds per cubic inch	1.08	0.99	1.09	1.89	1.80	1.05	0.91	0.97	.94	1.72	1.79	.86
Work to maximum load	do	7.6	7.7	.99	5.8	7.0	.83	5.8	7.3	.80	5.6	6.6	.85
Work total	do	14.0	15.1	.93	8.2	9.3	.87	7.6	13.4	.57	6.4	8.4	.75
Impact bending (50-pound hammer):													
Specific gravity		0.402	0.400	1.00	0.422	0.411	1.03	0.348	0.382	.91	0.362	0.394	.92
Fiber stress at elastic limit	Pounds per square inch	8,510	8,710	.98	9,050	9,940	.91	7,340	8,470	.87	9,430	9,650	.98
Modulus of elasticity	1,000 pounds per square inch	1,290	1,429	.90	1,595	1,796	.89	1,137	1,358	.84	1,400	1,640	.85
Work to elastic limit	Inch-pounds per cubic inch	3.1	3.0	1.03	3.0	3.2	.94	2.7	3.0	.90	3.6	3.3	1.09
Drop causing complete failure	Inches	21.0	22.0	.95	17.3	20.0	.87	15.8	20.0	.79	15.9	18.4	.87
Compression parallel to grain:													
Specific gravity		0.383	0.379	1.01	0.420	0.405	1.04	0.334	0.364	.92	0.358	0.388	.92
Crushing strength at elastic limit	Pounds per square inch	3,370	3,980	.85	4,320	5,020	.86	2,840	3,600	.79	3,810	4,680	.81
Maximum crushing strength	do	4,050	4,330	.94	6,360	6,370	1.00	3,430	4,050	.85	5,440	6,030	.90
Modulus of elasticity	1,000 pounds per square inch	1,277	1,542	.83	1,425	1,582	.90	1,220	1,459	.84	1,285	1,530	.84
Compression perpendicular to grain:													
Specific gravity		0.394	0.392	1.00	0.418	0.403	1.04	0.346	0.373	.93	0.359	0.392	.92
Fiber stress at elastic limit	Pounds per square inch	490	513	.96	862	812	1.06	425	520	.82	671	800	.84
Shearing strength:													
Radial	do	728	774	.94	800	895	.89	732	751	.98	883	878	1.01
Tangential	do	835	758	1.10	882	890	.99	726	775	.94	833	882	.94
Average	do	782	766	1.02	841	892	.94	729	763	.96	858	880	.98
Tension perpendicular to grain:													
Radial	do	254	292	.87	181	218	.83	283	288	.98	223	229	.97
Tangential	do	237	252	1.02	229	231	.99	252	254	.99	256	245	1.04
Average	do	256	272	.94	205	224	.92	268	271	.99	240	237	1.01

[1] The second logs were from 20 to 32 feet above ground.

TABLE 11.—*Average mechanical properties of virgin-growth redwood as related to height in tree*—Continued

Description and property	Unit	Comparison of butt and second logs						Comparison of top and second logs					
		Green			Air-dried			Green			Air-dried		
		Butt logs	Second logs	Ratio butt to second logs	Butt logs	Second logs	Ratio butt to second logs	Top logs	Second logs	Ratio top to second logs	Top logs	Second logs	Ratio top to second logs
Hardness [2]													
Specific gravity		0.389	0.383	1.02	0.415	0.410	1.01	0.349	0.364	.96	0.360	0.394	.91
End	Pounds	570	538	1.06	782	780	1.00	488	536	.91	707	762	.93
Radial	do	427	390	1.09	509	501	1.02	345	378	.91	412	456	.90
Tangential	do	441	410	1.07	497	475	1.05	340	396	.86	401	435	.92
Average radial and tangential	do	434	400	1.08	503	488	1.03	342	387	.88	406	440	.91
Cleavage:													
Radial	Pounds per inch of width	173	185	.94	122	136	.90	181	183	.99	147	138	1.07
Tangential	do	173	157	1.10	156	145	1.08	170	162	1.05	168	151	1.11
Average	do	173	171	1.01	139	140	.99	176	172	1.02	158	144	1.10
Tension parallel to grain:													
Maximum tensile strength	Pounds per square inch	8,090	9,800	.83	10,660	10,980	.97	8,410	9,340	.90	8,280	10,310	.80
Toughness [3]													
Specific gravity		0.408	0.399	1.02	0.418	0.401	1.04	0.353	0.382	.92	0.363	0.386	.94
Radial	Inch-pounds per specimen	67.5	63.7	1.06	54.7	53.7	1.02	46.0	53.9	.85	38.0	47.1	.81
Tangential	do	99.1	111.7	.89	79.8	86.3	.92	71.2	95.8	.74	55.5	72.2	.77
Average	do	83.3	87.7	.95	67.2	70.0	.96	58.6	74.8	.78	46.8	59.6	.79

[2] Load required to embed a 0.444-inch ball to one-half its diameter.
[3] Specimens $\frac{7}{8}$ by $\frac{7}{8}$ by 10 inches, tested over an 8-inch span with loads applied on tangential face nearest the pith.

VARIABILITY IN THE STRENGTH OF REDWOOD

Table 12 lists the probable variation values of the specific gravity and several strength properties of virgin-growth and the second-growth redwood from second logs, representing material 8 to 30 feet above the ground. These values were calculated by the usual formula, as given on page 34.

TABLE 12.—*Percentage probable variation*[1] *in strength and related properties of an individual redwood specimen from the corresponding average*

Property	Virgin-growth redwood[2] (lot Nos. 6, 7, and 8)		Second-growth redwood[3]			
			Closely grown (lot Nos. 7 and 8)		Openly grown (lot Nos. 7 and 8)	
	Green	Air-dry[4]	Green	Air-dry[4]	Green	Air-dry[4]
Specific gravity, based on green or air-dry volume	8.7	8.1	7.0	6.9	10.5	10.3
Shrinkage:						
Radial	16.5	----	17.9	----	34.0	----
Tangential	15.2	----	16.0	----	17.0	----
Volumetric	11.1	----	15.7	----	10.2	----
Static bending:						
Fiber stress at elastic limit	14.9	12.8	10.8	10.8	20.8	17.2
Modulus of rupture	12.3	11.4	9.4	11.4	17.4	16.1
Modulus of elasticity	15.5	12.3	16.4	15.9	18.3	18.3
Work to elastic limit	31.7	21.0	17.6	14.8	28.8	20.7
Work to maximum load	20.0	21.9	20.3	24.9	25.3	31.3
Impact bending:						
Fiber stress at elastic limit	11.4	14.3	10.0	13.2	13.8	18.4
Work to elastic limit	14.6	25.8	14.4	23.1	17.9	25.5
Maximum drop (50-pound hammer)	14.2	18.2	18.4	26.1	28.1	31.2
Compression parallel to grain:						
Fiber stress at elastic limit	16.2	16.7	14.0	16.3	23.4	24.5
Maximum crushing strength	12.9	12.6	10.1	10.1	19.2	16.3
Compression perpendicular to grain:						
Fiber stress at elastic limit	22.2	20.8	14.5	15.4	32.5	20.8
Hardness:						
End	12.6	11.7	9.3	7.4	19.5	17.0
Radial and tangential	15.8	15.7	11.2	13.0	18.1	21.2
Radial only	15.3	16.1	12.0	13.5	18.7	21.8
Tangential only	16.0	15.2	9.8	11.9	16.8	19.0
Shear:						
Radial and tangential	11.6	17.6	7.8	9.2	16.1	17.4
Radial only	11.3	18.2	8.9	8.9	13.9	15.9
Tangential only	11.9	16.7	5.2	9.3	15.1	15.9
Toughness:						
Radial and tangential	35.4	29.0	32.8	35.1	37.1	29.1
Radial only	27.4	23.1	24.1	39.1	36.4	25.9
Tangential only	30.3	26.0	30.0	29.7	36.0	29.9
Tension parallel to grain	14.6	19.3	8.3	18.7	20.5	17.8

[1] Probable variation of the entire trees is about 1 to 2 per cent higher than shown here.
[2] Specimen taken 20 to 30 feet above the ground
[3] Specimen taken 8 to 16 feet above the ground
[4] Average moisture content of air-dry material varied from 10½ to 12 per cent for different tests.

The percentage probable variation of specific gravity is lower than that of any of the strength properties. Such properties as modulus of rupture, maximum crushing strength, and hardness have a percentage probable variation from one to two times that of the specific gravity. Shock resistance as measured by work to maximum load in static bending, maximum drop in impact bending and toughness are usually most variable, often having a percentage probable variation four times that of specific gravity.

Since the probable variation values in Table 12 are based on samples from the second logs only, they are somewhat lower (probably about 1 to 2 per cent) than would obtain for samples representing the entire trees. For example, if the table gives a value of 17 per cent, the probable variation of a random specimen from entire trees, or the species average, is probably 18 to 19 per cent.

EXPLANATION OF TERMS AND METHODS EMPLOYED

Air-dry.—Air-dry is a very general term and may mean any degree of dryness from about 6 per cent moisture, which may be obtained in very dry climates, to over 30 per cent moisture, as in timber dried to reduce its shipping

weight. The degree of dryness which will be attained in timber depends upon the species, size, and the conditions under which the material is dried, especially such as humidity, method of piling, shelter, and time of drying.

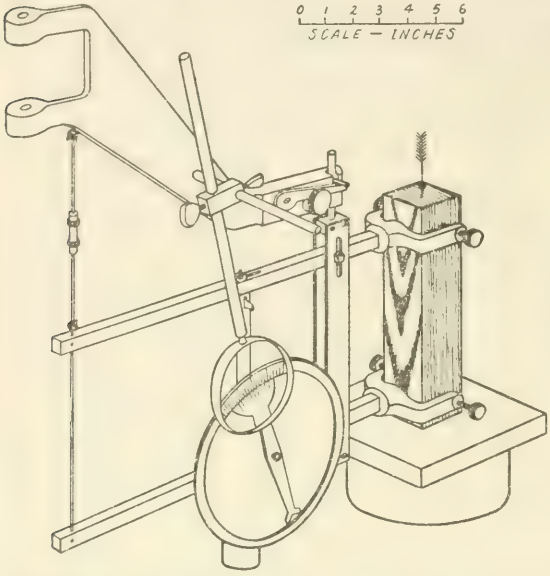


FIGURE 15.—Diagrammatic sketch of compressometer and method of conducting compression-parallel-to-grain test

Compression parallel to grain.—In the compression parallel to grain test a 2 by 2 by 8 inch block is compressed in the direction of its length. (Fig. 15.) Deformation is measured between two collars attached 6 inches apart on the specimen.

Compression perpendicular to grain.—In the compression perpendicular to grain test, a block 2 by 2 inches in cross section and 6 inches long is laid upon its side and pressure applied to it through a metal plate 2 inches wide laid across the center of the piece and at right angles to its length. (Fig. 16.) Hence but one-third of the surface is directly subjected to compression. The strength value obtained in this test is the fiber stress at elastic limit. It represents the maximum stress at right angles to the grain that can be applied to the timber without injury. It is important in computing the bearing area for beams, stringers, and joists, and in comparing species for railroad ties.

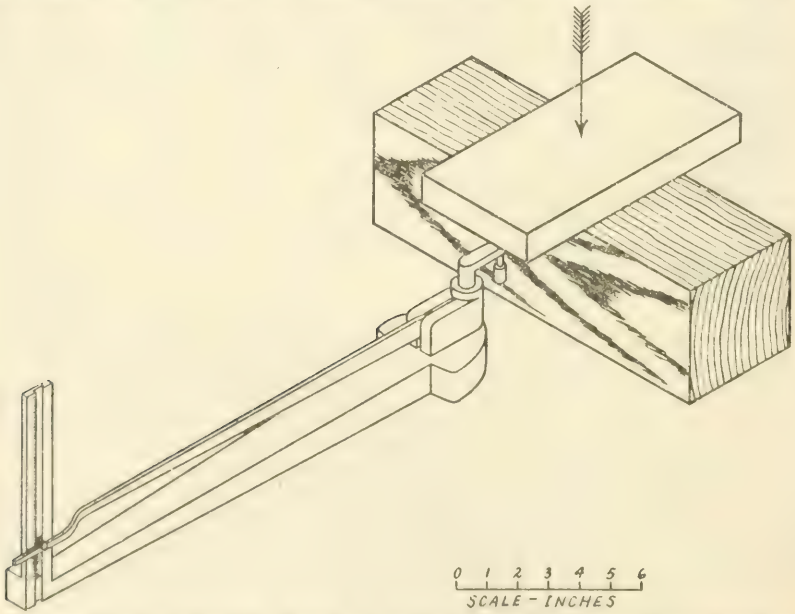


FIGURE 16.—Diagrammatic sketch of method of conducting compression-perpendicular-to-grain test

Elastic limit.—The elastic limit is that point where the distortion ceases to be in proportion to the load. For example, if a beam deflects one-sixteenth of an inch with a 50-pound load, it will deflect one-eighth of an inch with 100 pounds, and so on, each additional load of 50 pounds causing an additional deflection of one-sixteenth of an inch until the "elastic limit" is reached, after which the deflections increase more rapidly than the increase in load. The elastic limit is subject to the personal equation in its determination and for this reason can not be evaluated precisely.

Extractives.—Extractives, as the word is here used, are defined as that portion of the wood that will dissolve when the wood is placed in an inert solvent. They are known, for example, as cold-water, hot-water, or alcohol-soluble extractives, the name depending upon the solvent used.

Fiber stress at elastic limit.—Fiber stress at elastic limit is the stress obtained in a timber by loading it to its elastic limit. It is the greatest stress the timber will take under a given loading and return to its former position. Fiber stress at elastic limit in impact bending is approximately double the fiber stress at elastic limit in static bending. This is an expression of the fact that a small beam, if suddenly strained, bends approximately twice as far to the elastic limit as when loaded slowly. (See also elastic limit, above.)

Fiber-saturation point.—Green wood usually contains "absorbed" water within the cell walls and "free" water in the cell cavities. In drying, the water in the cell cavities is the first to be evaporated. The fiber-saturation point is that point at which no water exists in the cell cavities of the timber, but at which the cell walls are still saturated with moisture. The fiber-saturation point varies with the species. The ordinary proportion of moisture at the fiber-saturation point is from 22 to 30 per cent of the dry weight of the wood.

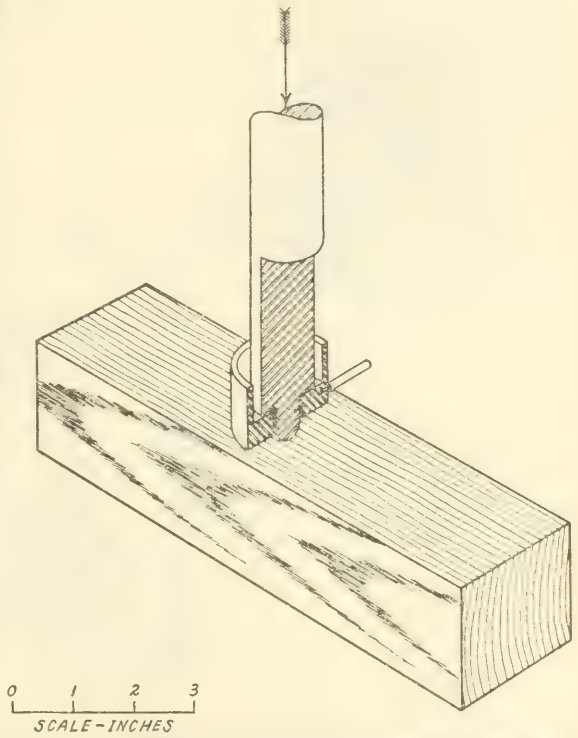


FIGURE 17.—Diagrammatic sketch of method of conducting hardness test

Green.—Green is the condition of timber with respect to moisture as taken from the living tree. Immediately upon being sawed from the tree, lumber begins to lose moisture and otherwise change its condition. The rapidity of these changes is determined by such factors as the species, humidity, heat, and circulation of air.

Hardness.—Hardness is tested by measuring the load required to embed a 0.444-inch ball to one-half its diameter in the wood. (Fig. 17.) The hardness test is applied to end, radial, and tangential surfaces of the timber. End hardness is usually greater than side hardness. The quality represented by the hardness figures is important in woods for paving blocks, railroad ties, furniture, and flooring.

Height of drop.—Height of drop relates to impact bending and is the distance from which a hammer is dropped to produce failure of a standard-sized specimen. It represents a quality important in articles that are occasionally stressed

under a shock beyond their elastic limit, such as handles and implement parts.

Impact bending.—Impact bending tests are made on beams to determine the resistance to rapidly applied loads. Beams 2 by 2 by 30 inches are used in this test on a 28-inch span. A 50-pound hammer is dropped upon the beam at the center of the span, first from a height of 1 inch, next 2 inches, and so on up to 10 inches, then increasing 2 inches at a time until complete failure occurs. The deflections of the specimen are recorded on a revolving drum by a pointer attached to the hammer. This pointer also records the position the specimen assumes after the shock. Thus data are obtained for determining the various properties of the wood when subjected to shock.

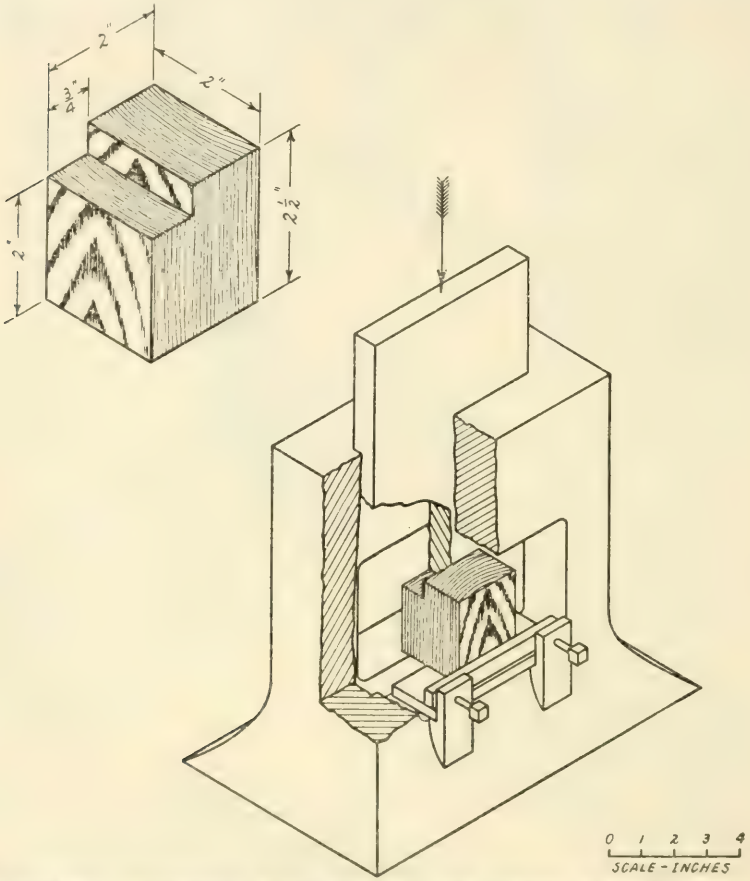


FIGURE 18.—Diagrammatic sketch of method of conducting shear-parallel-to-grain test, with details of test specimen

Maximum crushing strength.—The maximum crushing strength in compression parallel to grain is the maximum ability of a short block to sustain a slowly applied load. It is obtained by dividing the maximum load obtained in the test by the area of cross section of the block. This property is important in estimating the strength of short columns.

Mechanical properties.—Mechanical properties are the properties of wood which enable it to resist deformations, loads, shocks, or forces. Thus the ability to resist shearing forces is a mechanical property of timber.

Modulus of elasticity.—Modulus of elasticity is the ratio of stress per unit area to corresponding strain per unit length, the distortion or strain being within the elastic limit. It is a measure of the stiffness or rigidity of a mate-

rial. In the case of a beam, modulus of elasticity is a measure of its resistance to deflection. Deflection under a given load varies inversely as the modulus of elasticity; that is, a beam with a high modulus deflects but little. Modulus of elasticity is of value in computing the deflections of joists, beams, and stringers, and in computing safe loads for long columns. The values given are derived from the static-bending test, but are applicable to both beams and long columns. Numerically, the modulus of elasticity of a material is the force in pounds required to stretch a sample of that material with a cross-sectional area of 1 square inch to double its length, on the assumption that the fibers would not be stressed beyond their elastic limit. Rubber has a very low modulus of elasticity, while that of steel is very high.

Modulus of rupture.—Modulus of rupture is the computed fiber stress in the outermost fibers of a beam at the maximum load and is a measure of the ability of a beam to support a slowly applied load for a very short time. The formula by which modulus of rupture is computed is the same as that for computing the fiber stress at elastic limit, the maximum load being substituted for the elastic-limit load. The assumptions on which this formula are based hold only up to the elastic limit; hence modulus of rupture is not a true fiber stress. It is, however, a universally accepted term, and the values are quite comparable for various species and sizes of timber. It is a definite

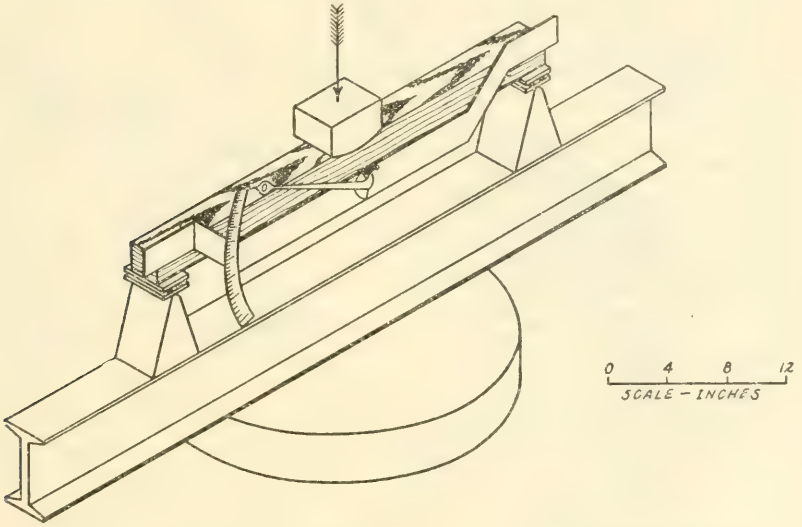


FIGURE 19.—Diagrammatic sketch of method of conducting static-bending test

quantity, and the personal factor does not enter to any great extent into obtaining it. It is consequently not so subject to error as the fiber stress at elastic limit, and for that reason is used more than any other value to represent the bending strength of wood.

Moisture content.—Moisture content is the weight of water contained in the wood, expressed as a percentage of the weight of the oven-dry wood.

Shearing strength parallel to grain.—The shearing test is made by applying force to a 2 by 2 inch lip projecting from the side of a block. (Fig. 18.) The shearing stress is the maximum force required to shear off the projection divided by the area of the plane of failure. Shearing strength parallel to the grain is a measure of the ability of timber to resist the slipping of one part upon another along the grain. Shearing stress is produced to a greater or less degree in most uses of timber. It is most important in beams, where it is known as horizontal shear, the stress tending to cause the upper half of the beam to slide upon the lower. It is also important in the design of various kinds of timber joints.

Shrinkage from the green to an oven-dry condition.—When wood is dried below the fiber-saturation point (see definition, p. 43), shrinkage begins and continues until the moisture is all driven off. Shrinkage along the length of timber is very small. Shrinkage in directions at right angles to the grain is

very much greater. Radial shrinkage is about three-fifths as great as tangential shrinkage. Shrinkage in volume is, of course, the resultant of shrinkages along the fibers and in the radial and tangential directions. However, shrinkage in volume and radial and tangential shrinkages were independently determined in the series of tests reported on in this bulletin. All shrinkage values given here are expressed in percentages of the original or green dimensions, and represent total shrinkage to a zero moisture condition. Shrinkage to an air-dry condition of about 12 per cent moisture is sometimes more and sometimes less than half the total shrinkage. Radial shrinkage is the measure of the change in width of a quarter-sawed or edge-grained board. Tangential shrinkage is the measure of the change in width of a flat-sawed board.

Site.—A site is an area considered with respect to its forest producing power as influenced by climate, altitude, soil, slope, aspect, and other local influencing conditions.

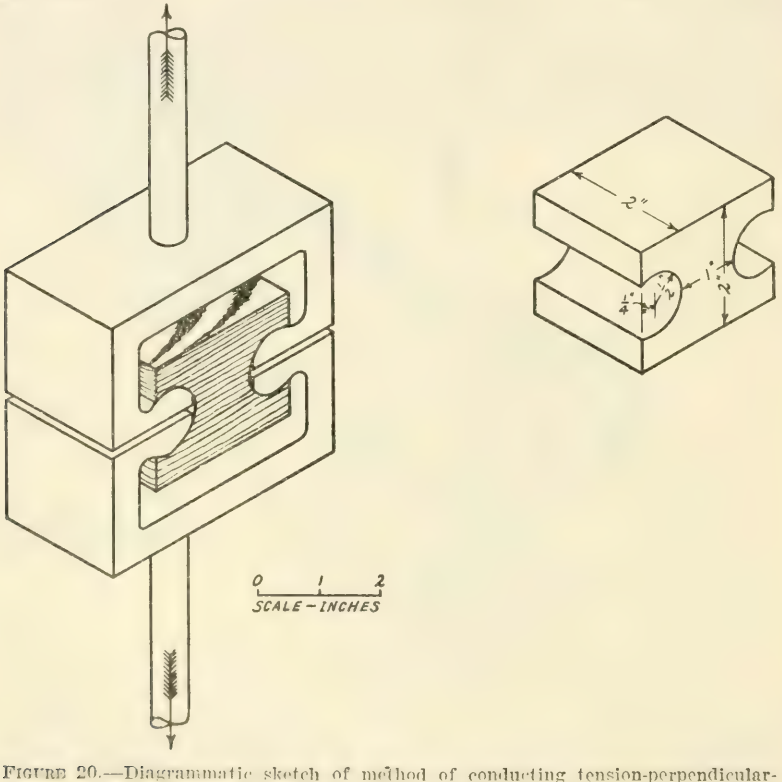


FIGURE 20.—Diagrammatic sketch of method of conducting tension-perpendicular-to-grain test, with details of test specimen

Specific gravity.—Specific gravity is the weight of any given substance divided by the weight of an equal volume of pure water at its greatest density. The weight of wood in a given volume changes with the shrinkage and swelling caused by changes in moisture. Consequently, specific gravity is an indefinite quantity unless the circumstances under which it is determined are specified. All specific gravity figures given in this bulletin are based on the weight of the wood when oven dry. The moisture condition at which the volume was determined is stated in each instance.

Static bending.—The static bending test is made on beams to determine the resistance to slowly applied loads. A 2 by 2 by 30 inch beam is used on a 28-inch span. Loading is applied at the center of the span and at a constant rate of deflection until the beam fails. (Fig. 19.) Readings of load and deflection are taken simultaneously. The values derived from this test are applicable to beams of different size by the use of a formula, except for the defects that occur in the larger sizes.

Strain.—The deformation or distortion produced by a stress or force is known as strain.

Stress.—Stress is distributed force. Fiber stress is the distributed force tending to compress, tear apart, or change the relative position of the wood fibers. Stress is measured by the force per unit area. Thus a short column 2 inches square (4 square inches) and supporting a load of 2,000 pounds will be under a stress or fiber stress of 500 pounds per square inch.

Tangential.—Tangential means tangent to or parallel to the curves of the annual rings in a cross section. Thus a tangential surface is a surface perpendicular to the radius of a tree.

Tension perpendicular to grain.—The tension-perpendicular-to-grain tests are made on specimens 2 inches square and 2½ inches long, the tension area being 1 by 2 inches. The tension force is applied perpendicular to the grain. (Fig. 20.) The values are of use in estimating the resistance of timber to the splitting actions of bolts and other fastenings.

Total work.—Total work in static bending, like work to maximum load, is a measure of toughness or shock resistance under bending stresses. In the

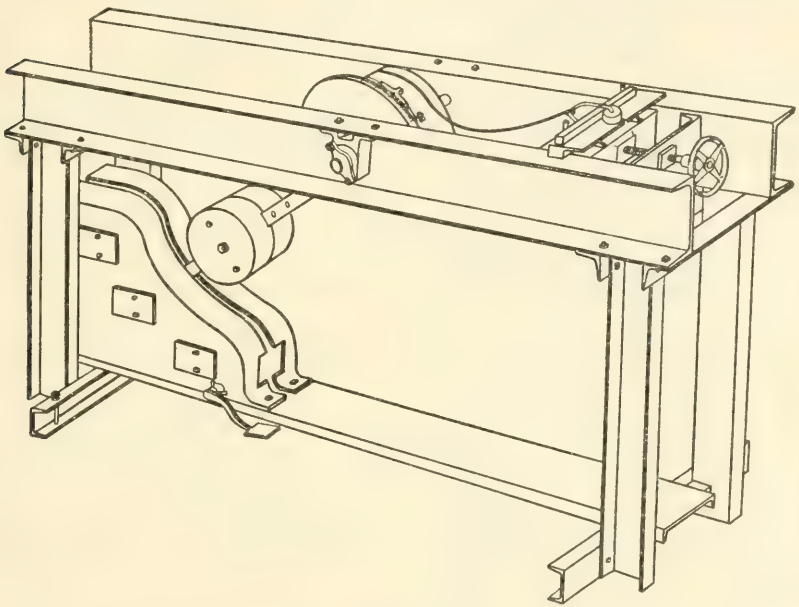


FIGURE 21.—Diagrammatic sketch of Forest Products Laboratory toughness testing machine

standard test specimen total work represents the work absorbed to a 6-inch deflection or until the beam fails to support a load of 200 pounds.

Toughness test.—The toughness test is made on small beams to determine the resistance to a rapidly applied load. The standard specimens for use in the test are ⅝ by ⅝ by 10 inches, supported over an 8-inch span. They are loaded at the center by means of a tup and a stirrup that slips over the specimen. (Fig. 21.) The Forest Products Laboratory toughness machine operates on the pendulum principle, but it differs essentially from other types in that the load is applied to the specimen by means of a cable fastened around a drum mounted on the axis of the pendulum.

Toughness.—Toughness in wood is the ability to absorb energy or work under load.

Work to elastic limit.—Work to elastic limit in bending is a measure of the work which a beam is able to resist or the shock which it can absorb up to the elastic limit.

Work to maximum load.—Work to maximum load in static bending represents the ability of the timber to absorb shock with a slight permanent or semi-permanent deformation and with some injury to the timber. Wood, especially

in small sizes, can be bent somewhat beyond its elastic limit with only slight injury if the load is removed at once. Work to maximum load is a measure of the combined strength and toughness of a material under bending stresses. Superiority in this quality is the characteristic which makes hickory better than ash, and oak better than longleaf pine, for such uses as handles and vehicle parts.

Radial.—Radial means extending outward from a center or an axis. Thus a radial surface in a tree is one extending from the pith of the tree outward, such as the wide faces of a quarter-sawed board.

Rings.—Rings are those circular markings around the center of a tree section that are produced by the contrast between spring wood and summer wood. One ring, known as an annual ring, consists of a layer of spring wood and a layer of summer wood.

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WASHINGTON, D. C.

AN ALINEMENT-CHART METHOD FOR PREPARING FOREST-TREE VOLUME TABLES

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CONTENTS

	Page
Introduction	1
The base chart for volume tables of entire stem in cubic feet	3
Assembly of the data	5
The first correction of the chart	6
The second correction of the chart	8
The third correction of the chart	14
Fourth and subsequent corrections of the chart	15
The number of approximations necessary	15
Final preparation of the volume table	15
Measures of accuracy of the final table	17
A permissible short cut in reading the second estimates	17
The order in which the corrections are made	17
Tables of volume in cubic feet of entire stem, including bark	19
Tables based on d. b. h. inside of bark	19
The form of base chart for merchantable volume in cubic feet	19
The form of base chart for merchantable volume in board feet	21
The technic in the case of the board-foot tables	24
The advantages of the alinement-chart method	28

INTRODUCTION

A volume table is a tabular statement of the average volume of trees of given sizes. The size classification is usually both by diameter (d. b. h. or diameter breast high, outside the bark) and height (either total or merchantable). This form of presentation implies that tree volume is correlated with both diameter and height.

If graphs are plotted showing the relation between volume and diameter for the several height classes and similarly between volume and height for the several diameter classes, curves rather than straight lines will result. This indicates that the preparation of a volume table is a problem in curvilinear multiple correlation.

A method of solving problems in curvilinear multiple correlation is described in a previous publication.[1] The technic is briefly as follows:

1. A multiple-regression equation is calculated, which is considered as a first approximation to the desired result.

2. This equation is converted into an alinement chart for ease in handling the subsequent steps. The alinement chart, being based on an equation of the first degree, has straight parallel axes and uniformly graduated scales.

3. Values are read from this chart corresponding to the data. These are called first estimates, and the differences between these

[1] BRUCE, D., and REINEKE, L. H. CORRELATION ALINEMENT CHARTS IN FOREST RESEARCH. U. S. Dept. Agr. Tech. Bul. 210, 88 p., illus. 1931.

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estimates and the corresponding measured values of the data are called first residuals.

4. The first residuals are plotted over the independent variables, one at a time, and curves are fitted.

5. These curves are used to regraduate the chart axes for these independent variables wherever changes are seen to be desirable.

6. Second estimates are read from the revised chart which represents a second approximation.

7. The measured values are then plotted over these second estimates, and a curve is fitted.

8. By means of this curve the graduations of the axis representing the dependent variable are relocated if necessary, thus producing a third-approximation chart.

9. These steps—4 to 5, and 6 to 8—are then alternately repeated as many times as may be necessary until a satisfactory result is obtained.

While volume-table construction is obviously a problem in curvilinear multiple correlation, it is a type of problem which requires a specialized form of the general technic.[2] The specialized technic, which brings speed and accuracy, will be described in the following pages.

The multiple-regression equation used in the general technic can be shown on theoretical grounds to be a poor first approximation in the case of a volume table. In the first place we know that the curves of volume over diameter and volume over height are not straight lines, so that varying spacing of the graduations of the diameter and height axes are to be expected. In the second place, from the familiar formula

$$V = FHB$$

where V is the volume in cubic feet, F the form factor, H the height in feet, B the basal area in square feet, we would expect to need a chart involving multiplication rather than the addition characteristic of a multiple-regression equation. Obviously, for rapid definition of the true relationships between volume, diameter, and height, a first-approximation chart which is much closer to the final result than one based on the multiple-regression equation is needed.

The best form of base chart or first-approximation chart is that which gives the volumes of a geometric solid most closely approaching tree form. For tables giving volume in cubic feet this condition is satisfied by a very simple chart, with three straight, parallel axes with logarithmically spaced graduations. The use of the board-foot unit of volume, however, makes necessary far more complex forms with curved axes. These forms differ with the log rule used, with the height index adopted (merchantable or total), and with the standard of top utilization. After the proper base chart has been prepared or selected, however, the subsequent procedure is essentially the same for all volume tables. It will therefore be possible to describe in detail the method for the cubic-foot tables, and then merely to refer to a few minor variations in connection with the other types of tables.

[2] Examples worked out by the general technic resulted in distorted tables only half as accurate as those prepared by the more usual methods.

THE BASE CHART FOR VOLUME TABLES OF ENTIRE STEM IN CUBIC FEET

Reference has already been made to the familiar formula for the volume of a tree in cubic feet

$$V = FHB = \frac{\pi FHD^2}{4 \times 144}$$

The corresponding formula for a cylinder having the same basal diameter and height is of course

$$V = \frac{\pi HD^2}{4 \times 144}$$

One familiar with the construction of alinement charts will at once think of more than one form of chart by means of which this equation might be solved.[3]

The simplest is one having three parallel straight axes, with the central axis halfway between the outside axes. All the scales are logarithmic to provide for the fact that the variables in the equation are to be multiplied together instead of added. One of the outer axes, then, is graduated with the values of log H, the other with values of log $\frac{\pi D^2}{4 \times 144}$, while the central is graduated with values of log V, using one-half of the scale used for the outer axes.

Such a chart will give volumes of cylinders of sizes corresponding to the trees for which data are at hand. Were the form factor a uniform factor for each species, all that would remain would be to raise the central or volume axis by an amount equal to the logarithm of this form factor. This follows from the fact that a bodily raising of the axis is equivalent to moving the slide in a slide rule. Unfortunately, however, the form factor varies with both diameter and height and that in a rather complex fashion. This type of adjustment of the central axis, therefore, while useful, would by no means be final, and would merely leave us with a first-approximation chart which was numerically closer than that for the cylinder, but no better in relation to variation in form factor. A cylinder chart, then, except for the larger numbers involved, is just as useful as one corrected for average form factor for the species. However, to gain some advantage in reduction in size of numbers, the cylinder chart used as the standard base chart is modified for a form factor of 0.4, which is a rough approximation to the average of all species.

This standard base chart used by the Forest Service is illustrated in Figure 1. The diameter axis is at the left, the height axis at the right, and the volume axis in the middle. To secure height and diameter axes of approximately the same length different scales have been used on these two axes, and as a result the volume axis is to the left of the central position.

The series of diagonal curves crossing the chart need explanation. These are the graduating curves used in constructing the chart, which are retained because of their usefulness in subsequent readjustments. They consist of four series, identified by the initials

[3] See the following publication: BRUCE, D., ALINEMENT CHARTS IN FOREST MENSURATION, Jour. Forestry 17: 773–801, illus., 1917; or such texts as LIPKA, J., GRAPHICAL AND MECHANICAL COMPUTATION, 264 p., illus., New York, 1918.

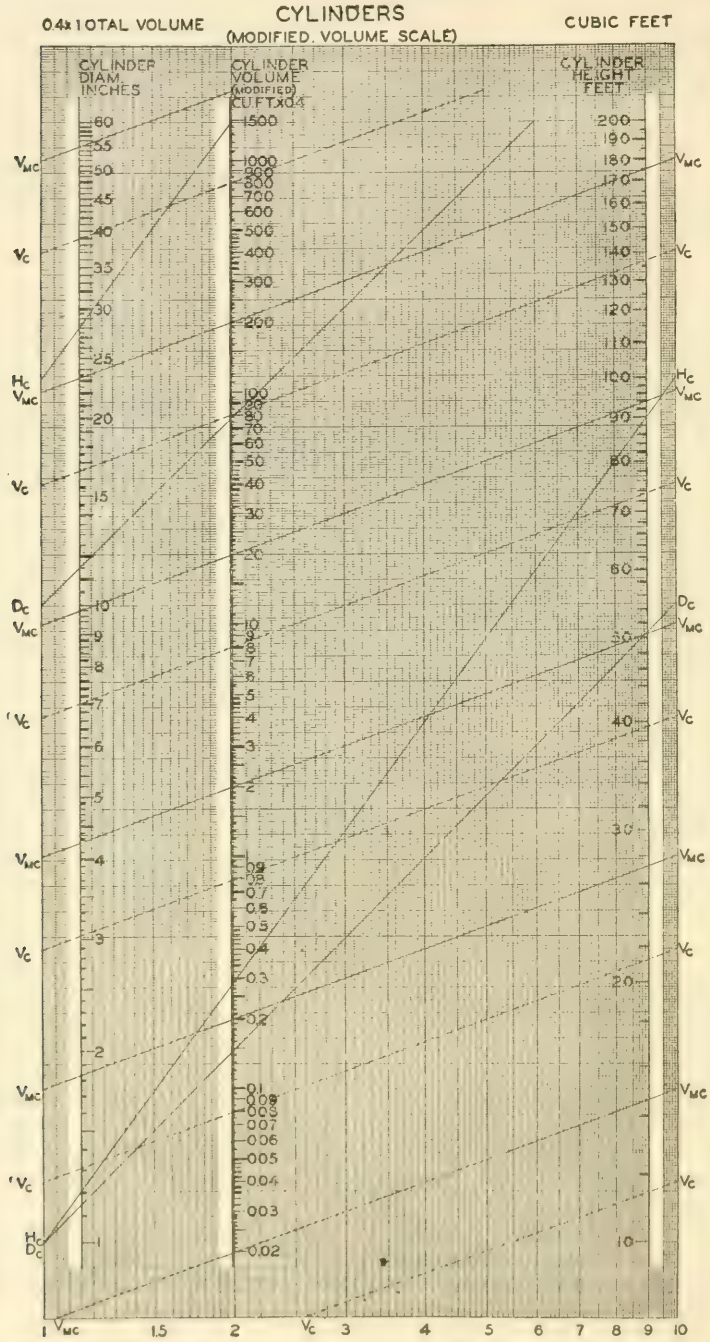

FIGURE 1.—The base chart used for volume tables in cubic feet (entire volume of stem)

D_c, H_c, V_c, and V_{mc}—standing, respectively, for diameter of cylinder, height of cylinder, volume of cylinder, and volume of modified cylinder.

They can best be understood if one series, for example, the D_c series, be carefully examined. It will be noted that the entire alinement chart is superposed on a sheet of semilogarithmic coordinate paper and that the vertical lines of this paper are given a scale across the base of 1 to 10. This scale is used in connection with all the graduating curves. Like all logarithmic scales, it applies equally well to values from 1 to 10, 10 to 100 or 100 to 1,000, etc. The semilogarithmic paper is used because on it the graduating curves will have very little curvature.

If the eye follows up the vertical line marked 1 (the left-hand edge of the chart) until it intersects for the first time the D_c curve, it will be noted that this intersection is horizontally opposite the 1 graduation on the diameter axis. Similarly, if the eye follows the 1.5 vertical to its intersection with the D_c curve, this intersection will be found opposite the 1.5 diameter graduation. The same will be found to be true for all possible values from 1 to 10. At 10 the D_c curve runs off the right-hand side of the chart. It reappears, however, opposite this point on the left-hand side, and this portion will be found to apply to diameter values of 10 or larger.

The D_c graduating curve, then, registers exactly the positions of all the graduations on the diameter axis. Were these graduations obliterated they could be accurately restored by means of the curve. Furthermore, if finer graduations should be needed for any purpose, they could easily and accurately be inserted by using this curve.

In a similar manner the H_c curve registers the graduations on the height axis. The lower portion of this curve, however, applies to heights of from 10 to 100, and the upper to heights above 100. The V_{mc} curve applies in the same way to the volume axis, but this is in six sections because of the large range of volume involved. The lowest section applies to volumes from 0.01 to 0.10 cubic foot and the highest to 1,000 cubic feet or more.

The V_c curves apply to nothing on the alinement chart but can be used to graduate the volume axis so that it will give cylinder volumes, if a cylinder-volume chart is desired.

It will also be noted that all coordinate lines have been removed from the chart in narrow strips along each of the axes. This is to permit the entry of new graduations as the work progresses, for it will be possible to make one copy of the chart serve throughout the entire process of the preparation of one volume table.

The charts actually used are considerably larger than Figure 1. The precise size is, of course, immaterial, but those used by the Forest Service are approximately 10 by 20 inches.

ASSEMBLY OF THE DATA

With one of these charts at hand, the first step in the actual preparation of a volume table is to assemble the existing data, which it is assumed have been collected in the field in the usual way. The tree sheets should be sorted into 1-inch (or sometimes 2-inch) diameter classes, and then subsorted into 10-foot (or sometimes 5-foot

or 20-foot) height classes.[4] A convenient form for tabular assembly is shown in Table 1, which is but the first sheet of several which are required. Each tree occupies a line, with the original data in the first four columns. It will be noted that three spaces are left after each d. b. h.-height class, two for totals and averages and one to separate the classes. By measured volume is meant the volume obtained from the field measurements by scaling, by computation, or by planimetering taper graphs.

THE FIRST CORRECTION OF THE CHART

The next step is to fill column 5 of Table 1 by use of the base alinement chart. For each tree a first-estimate volume is obtained

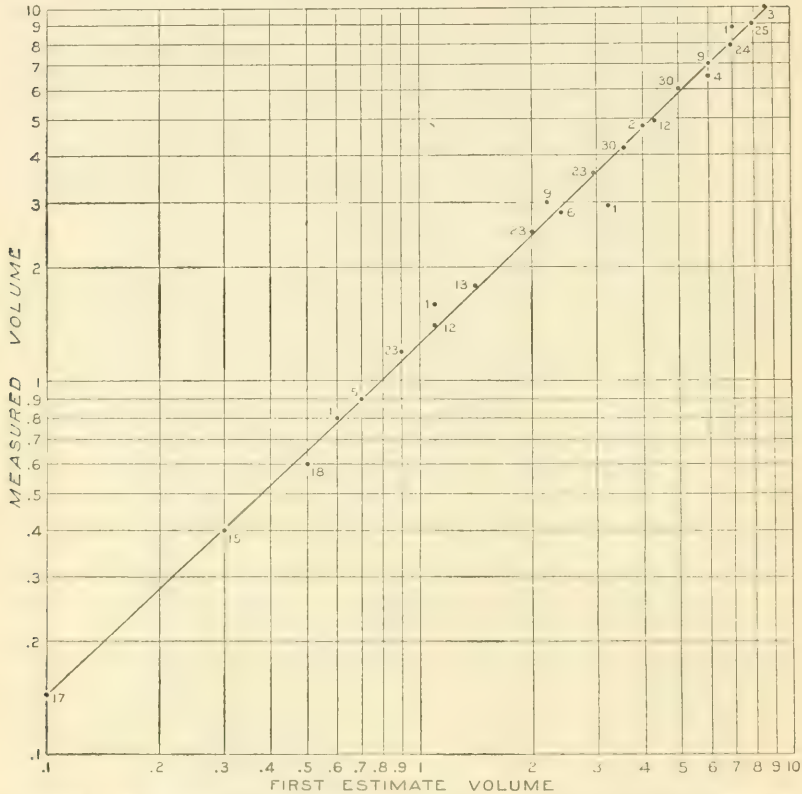

FIGURE 2.—The *measured—first estimate* curve based on columns 4 and 5 of Table 1. By means of this the V_{me} graduating curve of Figure 1 is readjusted

by extending a straightedge [5] from a point on the left-hand axis corresponding to the diameter to a point on the right-hand axis

[4] Two methods of sorting are almost equally usable; the 8-inch diameter class, for example, may include trees from 7.5 to 8.4 inches or trees from 8.0 to 8.9 inches. The average diameter in the first case will be close to 8.0 and in the second close to 8.5. In the final volume table, volumes will be entered for 8. rather than 8.5, but it does not follow from this fact that there is any advantage in the first system of sorting. In plotting, the actual average diameters can and should be used, and the final results may be read from curves or alinement charts for even-inch diameters. When hand sorting by the second method, tenths of inches are ignored, thus eliminating errors in classifying, and increasing speed. Where punched cards are used in connection with tabulating machinery, sorting is somewhat simplified by the 8.0-8.9 classification, and this has therefore been made standard by the Forest Service.

[5] A stiff strip of transparent celluloid with a fine straight line etched on it is preferable to a straightedge because shadows are eliminated.

corresponding to the height, and reading its intersection with the central axis. When all volumes have been so obtained, both measured and first-estimate volumes are totaled and averaged for each d. b. h.-height class. The averages [6] are then plotted on logarithmic cross-section paper, with measured values on the vertical and first-estimates on the horizontal scale, and a curve is fitted. A characteristic result is shown in Figure 2. This is not the entire curve. The lowest point

TABLE 1.—*Chestnut volume table computation form*

Tree No.	Diameter breast high	Total height	Volume						Deviation (per cent of last estimate)
			Measured	Estimate					
				First	Second	Third	Fourth	Fifth	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Inches	*Feet*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	
16	1.0	15	0.05	0.03	0.04	0.04			25
17	1.0	16	.05	.04	.05	.05			0
18	1.0	17	.05	.04	.05	.05			0
19	1.0	18	.06	.04	.05	.05			20
20	1.1	15	.07	.04	.05	.05			40
21	1.1	16	.07	.04	.06	.06			17
22	1.1	16	.07	.04	.06	.06			17
23	1.2	16	.07	.05	.07	.07			0
24	1.2	16	.07	.05	.07	.07			0
25	1.2	15	.08	.05	.07	.07			14
26	1.2	16	.08	.05	.07	.07			14
28	1.2	16	.09	.05	.07	.07			29
30	1.2	19	.10	.06	.09	.09			11
27	1.3	16	.10	.06	.09	.09			11
29	1.3	18	.10	.07	.10	.10			0
31	1.4	16	.08	.07	.10	.10			20
33	1.4	16	.09	.07	.10	.10			10
32	1.4	18	.10	.08	.11	.11			9
35	1.4	18	.11	.08	.11	.11			0
36	1.4	19	.11	.08	.12	.12			8
34	1.5	18	.12	.09	.13	.13			8
37	1.6	16	.12	.09	.13	.13			8
54	1.7	16	.17	.10	.15	.15			13
53	1.8	18	.17	.13	.18	.18			6
55	1.9	17	.19	.13	.19	.19			0
Total [a]	32.6	417	2.37	1.63	2.31	2.31			
Average	1.3	17	.09	.07	.09	.09			
38	1.1	20	.08	.05	.07	.07			14
39	1.1	20	.08	.05	.07	.07			14
40	1.3	20	.10	.07	.11	.11			9
41	1.3	20	.11	.07	.11	.11			0
42	1.3	23	.13	.08	.12	.12			8
46	1.4	20	.13	.08	.13	.13			0
44	1.4	21	.13	.09	.13	.13			0
47	1.4	21	.14	.09	.13	.13			8
48	1.4	23	.14	.10	.14	.14			0
45	1.4	23	.15	.10	.14	.14			7
49	1.4	25	.16	.10	.15	.15			7
50	1.6	22	.19	.12	.18	.18			6
51	1.6	24	.16	.13	.19	.19			16
52	1.7	20	.18	.13	.18	.18			0
56	1.8	22	.24	.16	.22	.22			9
57	1.8	23	.24	.16	.23	.23			4
58	1.9	21	.23	.16	.24	.24			4
Total [b]	24.9	368	2.59	1.74	2.54	2.54			
Average	1.5	22	.15	.10	.15	.15			

[a] Total, 25 trees. [b] Total, 17 trees.

[6] The individual values instead of the averages could, of course, be plotted, but the labor would be great and the curve fitting more difficult. There is, moreover, a theoretical advantage in resorting the values, both measured and estimated, on the basis of the first estimates, before averaging and plotting, but in most cases the increased accuracy of the result is not enough to justify the additional labor. The use of d. b. h.-height classes is equivalent to a rough sorting by first estimates, in which adjacent groups more or less overlap, but appreciable errors can hardly be caused by this rough sorting, because the resulting curves will be nearly straight lines.

on the curve, however, may be identified as that based on the second group in Table 1. It will be seen that the curve is very nearly a straight line and that the definition is excellent. The logarithmic paper is used merely because of the difficulty of plotting and reading the smaller values on ordinary paper; the shape of the curve would be the same on regular coordinate paper.

Were the curve a 45° straight line passing through the points (1, 1) (10, 10), etc., this would indicate that the first estimates agreed on the whole with the measured values and that the original chart was satisfactory without alteration. Usually this is not the case, and the curve, instead of confirming the chart, becomes a means of correcting it.

The simplest way to perform this correction is to revise the graduating curve V_{mc} first and then to use this revised curve to regraduate the volume axis. The method is as follows:

From Figure 2 it can be seen that for a first estimate of 0.1 cubic foot the corresponding measured (or "true") volume is 0.146.[7] The 0.1 point on the V_{mc} curve (fig. 3), which is its intersection with the vertical representing 0.1, must therefore be shifted horizontally to the vertical representing 0.146. Similarly, the point where it intersects the 0.2 vertical must be shifted to the vertical representing 0.28, etc. When enough of the points on the curve have been thus shifted, a revised graduating curve can be drawn through their new positions. By using this graduating curve, a new set of graduations can be entered on the blank or left side of the volume axis. The new graduating curve can be seen in Figure 3, marked V_1,[8] as well as the new volume graduations which correspond to it.

It is advisable to enter these new graduations in soft pencil so they may be erased if further revision is later found necessary. The graduating curve itself should therefore be inked in for permanent record. To avoid confusion between the various graduating curves which will eventually appear on the one chart, various colors are almost indispensable.

THE SECOND CORRECTION OF THE CHART

A set of second estimates of volume are next read from the revised chart and entered in column 6 of Table 1. These should, on an average, be much closer to the measured volumes than the first estimates.

Since a change in the volume scale has resulted in a closer agreement with the basic data, it is obvious that further improvement might be obtained by changes in either the diameter scale, the height scale, or both. The first of these possibilities is investigated by summarizing by diameter classes, disregarding height, the height-diameter class totals of certain items. These may appear in the form shown in Table 2, which like Table 1 is incomplete. Table 2 is summarized in complete form, however, in Table 3.

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[7] So accurate a reading is of course impossible in Figure 2 as here shown. This figure is greatly reduced in scale from that actually used, and this reduction has made it necessary to omit most of the vertical and horizontal rulings.

[8] Subscripts denote the estimate from which the revised graduation curve was derived.

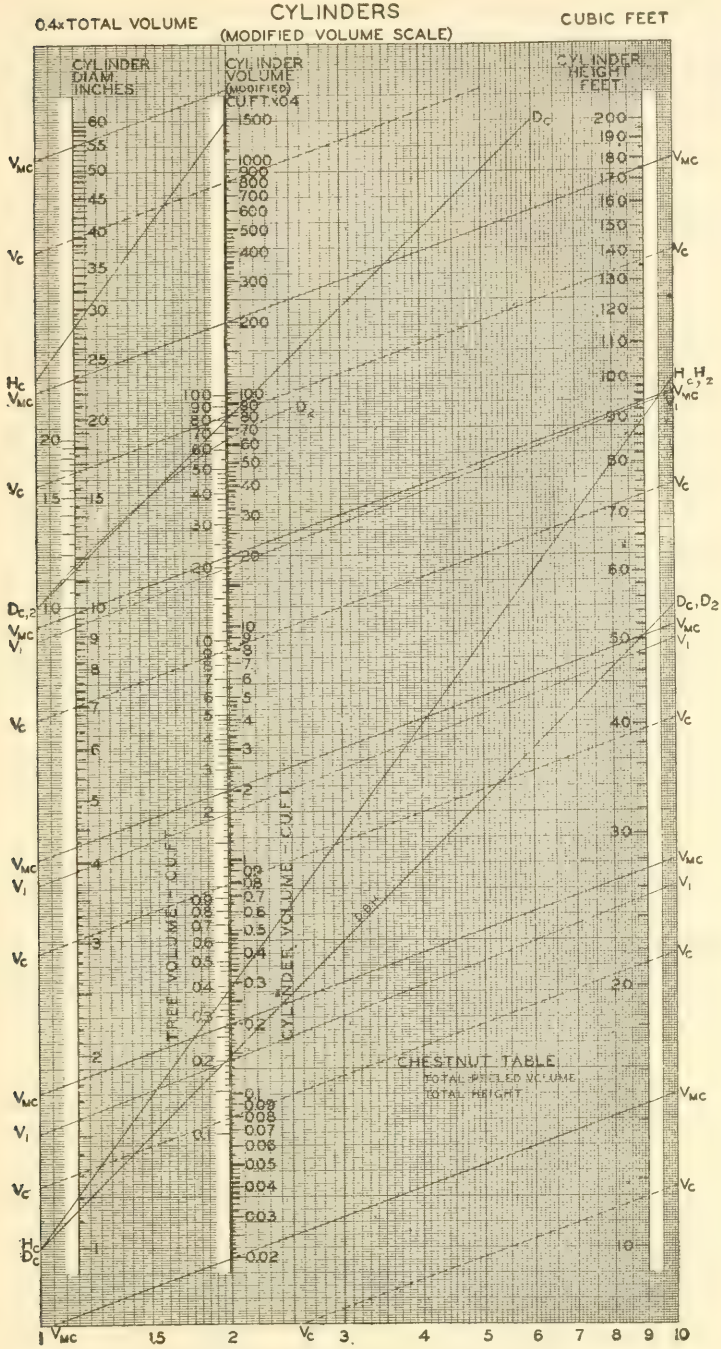

FIGURE 3.—The final appearance of the base chart

TABLE 2.—*Recapitulation by diameter classes after second estimate*

Diameter breast high class (inches)	Total height class	Trees	Totals of—			Difference of second estimate	New graduation distance
			Diameter breast high	Second estimate volume	Measured volume		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Feet	*Number*	*Inches*	*Cu. ft.*	*Cu. ft.*	*Per cent*	
1.0–1.9	10–19	25	32.6	2.31	2.37		
	20–29	17	24.9	2.54	2.59		
Total		42	57.5	4.85	4.96	+2.3	
Average			1.4	1.15	1.18		1.4
2.0–2.9	20–29	15	35.0	6.3	6.6		
	30–39	18	46.5	11.7	11.4		
	40–49	1	2.7	.8	.8		
Total		34	84.2	18.8	18.8	0.0	
Average			2.5	.553	.553		2.5
3.0–3.9	20–29	5	17.2	4.4	4.7		
	30–39	23	80.8	27.0	27.0		
	40–49	12	41.7	17.3	17.2		
Total		40	139.7	48.7	48.9	+0.4	
Average			3.5	1.22	1.22		3.5
4.0–4.9	20–29	1	4.5	1.4	1.6		
	30–39	13	56.3	23.0	23.3		
	40–49	23	103.9	55.4	56.5		
	50–59	9	39.9	23.9	26.9		
	60–69	1	4.9	3.8	2.9		
Total		47	209.5	107.5	111.2	+3.4	
Average			4.5	2.29	2.37		4.6
5.0–5.9	30–39	6	31.8	17.4	17.1		
	40–49	23	122.4	79.5	82.5		
	50–59	30	165.8	128.4	126.9		
	60–69	2	10.9	9.4	9.5		
Total		61	330.9	234.7	236.0	+0.6	
Average			5.4	3.85	3.87		5.4
6.0–6.9	40–49	12	77.3	60.8	58.6		
	50–59	30	194.4	178.3	178.6		
	60–69	9	58.6	63.1	62.7		
	70–79	1	6.5	8.1	8.8		
Total		523	36.8	310.3	308.7	−0.5	
Average			6.5	5.97	5.94		6.5

TABLE 3.—*Summary of Table 2 for all diameter classes* [1]

Trees (number)	Aggregate diameter breast high	Volume				Difference,[2] measured—second estimate	Diameter breast high	
		Aggregate		Average			Average	New graduation distance
		Second estimate	Measured	Second estimate	Measured			
	Inches	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Per cent*	*Inches*	*Inches*
42	57.5	4.85	4.96	0.115	0.118	+2.3	1.4	1.4
34	84.2	18.8	18.8	.553	.553	0.0	2.5	2.5
40	139.7	48.7	48.9	1.22	1.22	+.4	3.5	3.5
47	209.5	107.5	111.2	2.29	2.37	+3.4	4.5	4.6
61	330.9	234.7	236.0	3.85	3.87	+.6	5.4	5.4
52	336.8	310.3	308.7	5.97	5.94	−.5	6.5	6.5
59	442.1	498.4	488.9	8.45	8.29	−1.9	7.5	7.4
64	543.6	727.2	729.8	11.4	11.4	+.4	8.5	8.5
59	554.3	867.6	881.3	14.7	14.9	+1.6	9.4	9.5
58	604.5	1,068.4	1,077.2	18.4	18.6	+.8	10.4	10.5
63	719.6	1,415.4	1,453.4	22.5	23.1	+2.7	11.4	11.6
33	408.4	847.8	857.0	25.7	26.0	+1.1	12.4	12.5
28	377.6	834.6	866.0	29.8	30.9	+3.8	13.5	13.7
21	302.0	744.3	753.1	35.4	35.9	+1.2	14.4	14.5
23	355.9	934.6	939.0	40.6	40.8	+.5	15.5	15.5
15	246.7	716.4	690.9	47.8	46.1	−3.6	16.4	16.1
3	52.3	142.1	128.6	47.4	42.9	−9.5	17.4	16.4
2	37.1	120.4	111.2	60.2	55.6	−7.6	18.6	17.8
701		9,642.05	9,704.96					

[1] This condensed form is the one actually used, but Table 2 illustrates better how the data are combined.
[2] Computed from aggregate rather than average volumes.

Following the total-height classes under each height-diameter class in Table 2, three lines are left for totals, averages, and to separate the d. b. h. classes. When each height-diameter class has been entered, the diameter-class totals and averages are calculated and entered. The percentage differences between the measured and estimated volumes, using the estimates as the base, are then computed and entered in column 7.

The purpose of this step is to discover whether there is any residual correlation between the volume errors of the revised chart and diameter. If there were none, the percentages in column 7 would either all be approximately zero, or, what is more normally the case where the number of trees used is limited, would at least have no well-defined trend away from zero. In some cases this may be judged by inspection, but it will usually be necessary to plot the percentages of column 7 over the average diameters of column 4. A typical result is illustrated in Figure 4. It will be seen that there is in this case a fairly well-defined trend, which shows that the chart in its present form tends in particular to overestimate the volume of trees above 16 inches in diameter.

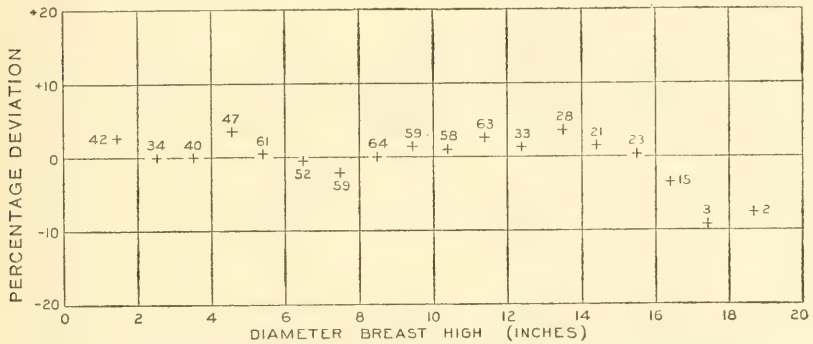

FIGURE 4.—Percentage deviations between measured and estimated (second) volumes over d. b. h. A correction of the diameter scale, particularly at the upper end, is indicated

If a change is necessary, the desired correction is accomplished by shifting each graduation on the diameter axis to such a position that the measured or "true" volumes will be read on the volume axis instead of the corresponding second estimates. This is done as follows:

For each of the diameter-class averages in Table 2 pass a line through the average d. b. h. (as shown in column 4 of the table) and the average second-estimate volume and hold its intersection with the height axis (this is in a sense the average height for this diameter class); then pivoting on this point, shift the line so that it passes through the average measured volume and note the diameter reading at which it intersects the diameter axis. This process is illustrated in Figure 5, which shows the procedure for the class averaging 18.6 inches, which has an average second-estimate volume of 60.2 and an average measured volume of 55.6. This gives the new position of the particular d. b. h. used, the graduation distance being expressed in terms of the original scale. The value noted, 17.8 in the instance illustrated, is entered in the last column of Table 2 or Table 3. Table 3 illustrates the form actually employed. Table 2 illustrates more completely the manner of combining the d. b. h.-height classes.

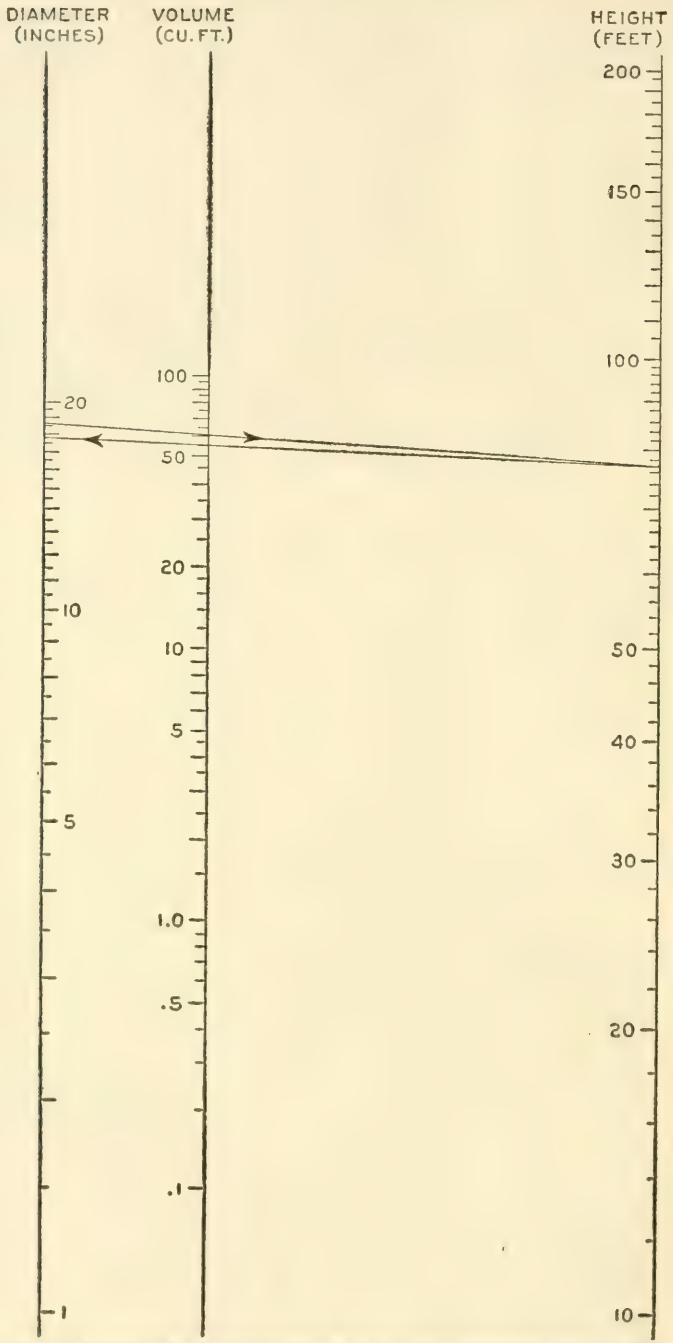

FIGURE 5.—Method of determining new graduation distances on diameter axis

The graduation distances thus determined are then plotted over the average d. b. h. of the class on regular coordinate paper, and a curve is fitted, as in Figure 6.

This curve may then be used to regraduate the diameter axis. For example, in Figure 6 the graduation distance for a d. b. h. of 18 inches is seen to be 17.3. The new position of the 18-inch graduation is therefore opposite 17.3 on the old scale, etc. This altered series of graduations should be entered in pencil, but may well be permanently recorded by means of a revised graduating curve in ink, labeled D_2.

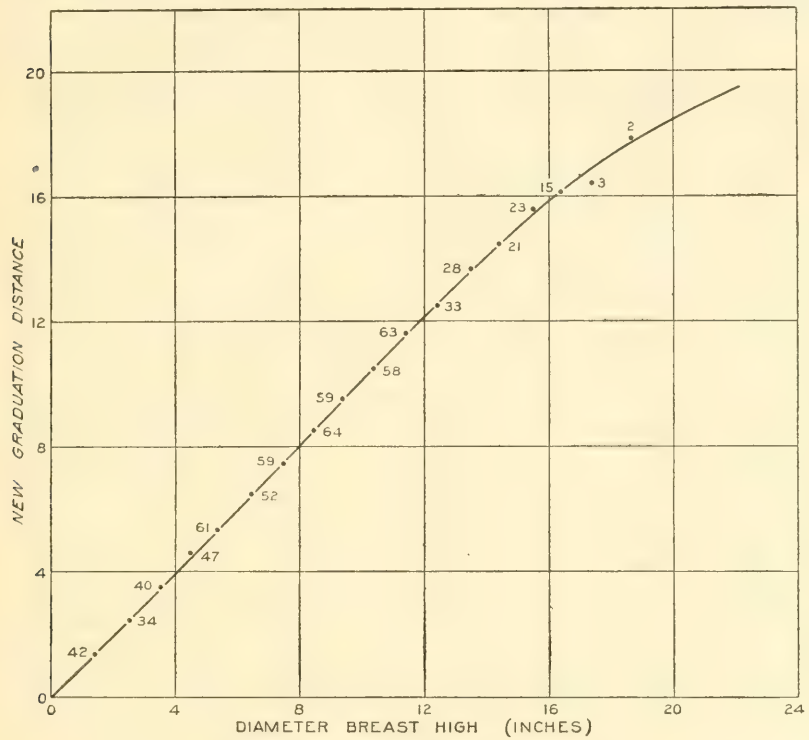

FIGURE 6.—Curve fitted to graduation distances derived by means of Figure 5

The curves of Figures 4 and 6 are merely two different expressions of the same facts. In the former a horizontal straight line indicates that no change need be made; in the latter a 45° straight line means the same thing. It is therefore desirable to omit Figure 4, and with it column 7 of Table 2, since the curve of Figure 6 not only indicates the need for change but also provides the mechanism for making it.

Before reading a new series of estimates, a similar process should be performed for height. The same information from the second estimate should be summarized by height classes, regardless of diameter. If any readjustments of the height scale are found to be necessary, they should be made exactly as for diameter. The process illustrated in Figure 5 is, however, now exactly reversed; a line is passed through each average height and average second-estimate

volume to an intersection with the diameter axis, which is held as a pivot, etc., etc. The resulting chart, which may have all three axes now modified, is considered a third approximation, and a series of third estimates is read and entered in column 7 of the original table. For the example at hand, no correction for the H axis was indicated. H_2 is, therefore, identical with H_c.

THE THIRD CORRECTION OF THE CHART

When column 7 has been totaled and averaged by height-diameter classes, a third correction may be made which is in every way similar to the first. The adjustment of the height and diameter axes may

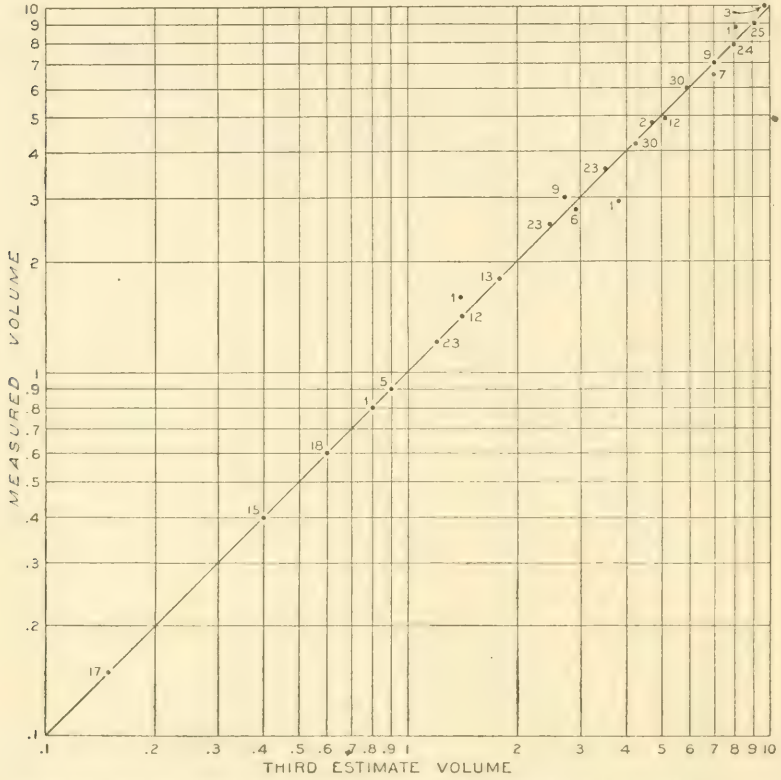

FIGURE 7.—The *measured—third estimate* curve based on columns 4 and 7 of Table 1. The 45° straight line indicates that no further revision is necessary

have thrown the volume axis out of adjustment, and this must be tested. Average measured volumes are therefore now plotted over average third estimates. The curve will resemble in general Figure 2, but will approach more nearly a 45° straight line. In the case which is being illustrated it is, indeed, exactly a 45° straight line, and this shows that no further improvement can be made. (Fig. 7.)

While this is a normal result, it sometimes happens that some curve or some line is defined which is not a 45° line passing through the (1, 1) point. In this case the volume scale must be recorrected,

using exactly the same process[9] as was used in making the first correction. This new graduation curve is labeled V_3. The first penciled corrections must be erased from the volume axis and new ones entered by means of the graduating curve V_3, which should be in ink as before.

The revision of the chart permits a series of fourth estimates to be read.

FOURTH AND SUBSEQUENT CORRECTIONS OF THE CHART

If the previous step has resulted in an alteration of the chart—other than that indicated by a 45° straight line, not through (1, 1) (10, 10) which merely raises or lowers the entire scale—a fourth correction should be made. This is similar in every way to the second correction, already described, except that the fourth estimates are used. Probably neither the height nor diameter axis can be further improved, but if any improvement is possible it should, of course, be made.[10] In this case a fifth correction similar to the first and third should be attempted.

In other words, the two types of correction described should be alternately applied until a stage is reached where no further correction is indicated. When this result has been attained the volume table is considered complete except for the translation of the chart into a table of the customary form.

The final appearance of the base chart in the case which has been illustrated is shown in Figure 3. The revised graduating curves for volume (V_1) and for diameter (D_2) will be seen, with the corresponding new scales on the volume and diameter axes.

THE NUMBER OF APPROXIMATIONS NECESSARY

Fortunately the technic described rarely requires many repetitions. In some of the cases which have been worked out by the Forest Service a single correction of the volume axis has been all that has been necessary, the attempt to make second corrections merely establishing this fact. It is rare to have to make more than three corrections. The process, then, is by no means laborious. The last estimate indicating completion of the chart is not wasted, since these values are needed for the checks to be made.

FINAL PREPARATION OF THE VOLUME TABLE

The final graduations of the chart are inked in, and if a volume table in alinement-chart form is desired, a tracing is made of the three axes only with their final scales. This may be reproduced photographically, in reduced size if desired. A typical result is shown in Figure 8. (The two diameter scales will be discussed later.)

A final table may also be read from the chart. The conventional tabular form is more convenient for most purposes, but the chart form is very useful in any work where interpolations in the table are necessary.

---

[9] Graduation curve V_1, rather than V_{mc}, is, of course, used in making this correction.

[10] The new graduation distances should be obtained from the diameter and height scales from the D_2 and H_2 graduating curves.

FIGURE 8.—The final volume table in alinement-chart form

MEASURES OF ACCURACY OF THE FINAL TABLE

It is customary to calculate two measures of accuracy for any volume table. These are the aggregate deviation and the average percentage deviation.

The aggregate deviation is merely the difference between the grand totals of the measured and last-estimated volumes (columns 4 and 7, Table 1) and is expressed as a percentage of the grand total of the measured volumes. It can be most clearly presented as follows:

Aggregate deviation: Chart ------ per cent high (or low).

This serves merely as a check on the accuracy with which the curves have been balanced and does not check the form of the curves, which depend on good technic in fitting the *measured-estimate* curves and the correction curves for height and diameter. If the aggregate deviation is less than 0.5 per cent for important tables and less than 1 per cent for secondary tables, the result is considered satisfactory.[11]

The average percentage deviation is computed from the measured and last-estimated volumes of the individual trees. The difference between the measured and last-estimated volume is expressed as a percentage of the estimated volume. Slide-rule accuracy is sufficient. An alinement chart which gives the percentage deviation directly from a setting of measured and estimated volumns is shown in Figure 9. The percentages may be entered in a final column of Table 1. Signs are disregarded. The percentages are totaled and averaged, and the result may be presented as follows:

Average percentage deviation, ------ per cent.

A PERMISSIBLE SHORT CUT IN READING THE SECOND ESTIMATES

In the foregoing pages it was stated that the second estimate should be read from the corrected base chart. It is somewhat easier to obtain these values indirectly from the first estimates by means of the measured-over-first-estimate curve. (Fig. 2.) For example, tree No. 54 in Table 1 has a first-estimate volume of 0.10. On Figure 2 it will be seen that the curve above 0.10 reads 0.15, and this can be entered as the second estimate. The results should be approximately identical with estimates read by means of d. b. h. and height from the corrected alinement chart, but being based on a single value (the first estimate) instead of on two values (the diameter and the height) they can be more quickly obtained. It is well to check a few values by both methods to insure against blunders in correcting the chart.

Similarly, fourth estimates may be read from the *measured—third estimate* curve.

THE ORDER IN WHICH THE CORRECTIONS ARE MADE

It may have been noted that in the procedure described, the order of the operations has been reversed from that which is normal in the more general method of curvilinear multiple correlation. The reason for this is that form factor usually is more closely correlated with volume than with either diameter or height. If the height and diameter axes are corrected first, curvature may be thrown into one

[11] SOCIETY OF AMERICAN FORESTERS (Committee on standardization of volume and yield tables). METHODS OF PREPARING VOLUME AND YIELD TABLES. Jour. Forestry 24:653, Item 37 (a). 1924.

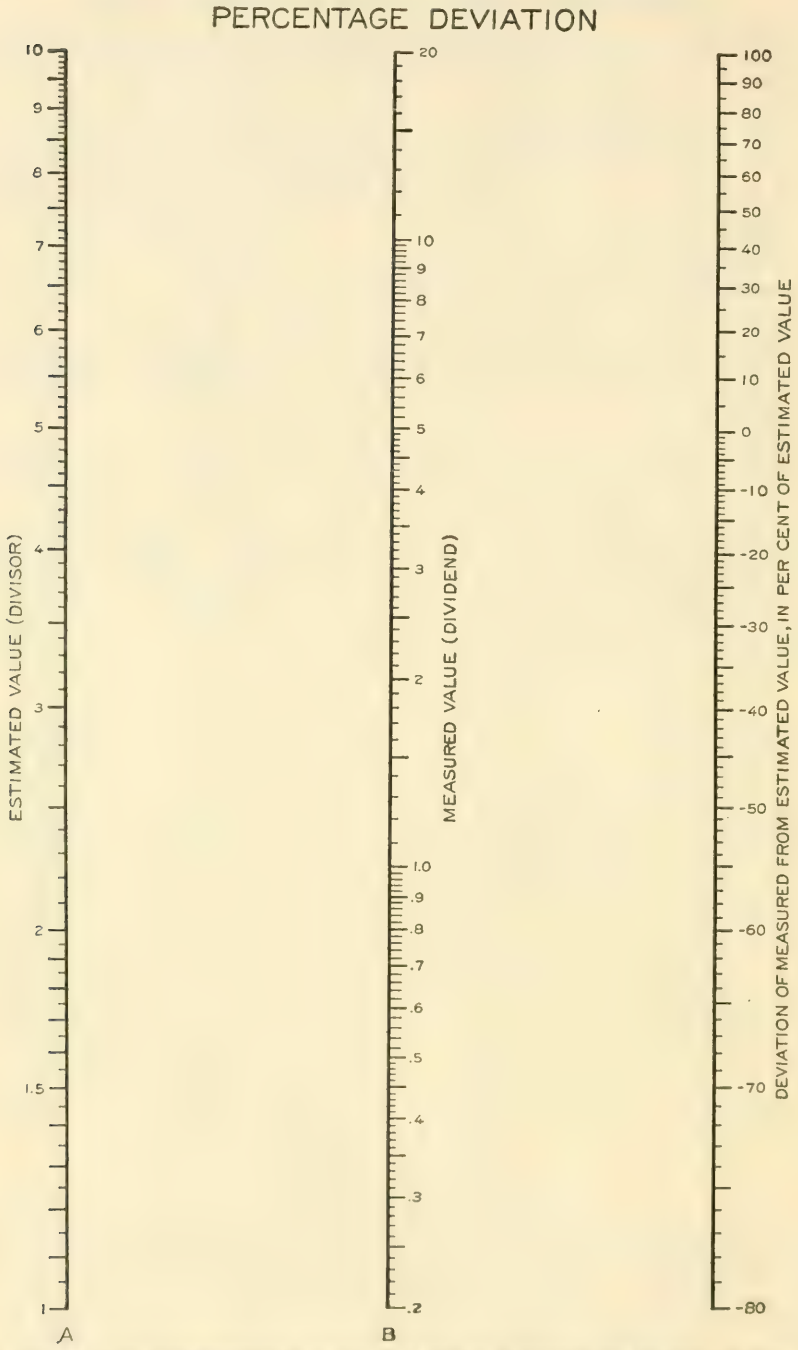

FIGURE 9.—This chart gives directly the percentage deviation of measured from estimated volumes without computation of differences

of their graduating curves which belongs in that for the volume axis. If this happens it may require several corrections to transfer it to the volume axis. In actual experience it has been found that several more estimates are usually required if the height and diameter axes are corrected first.

TABLES OF VOLUME IN CUBIC FEET OF ENTIRE STEM, INCLUDING BARK

If it is desired to make a volume table in which the stated volume is to include the bark the same base chart may be used. Since the geometrical solid on which the form factor is based is the same in either case, i. e., a cylinder having a diameter equal to the d. b. h. outside the bark, it is obvious that the form factor for the volume including bark will be higher than for that omitting it. It might theoretically be preferable, therefore, to use a slightly altered chart in which the "modified cylinder" volumes were those of a cylinder multiplied by some factor such as 0.45 instead of 0.40. In practice, however, the difference would be very slight and would appear merely as a slight horizontal displacement of the curve such as is illustrated in Figure 1, since the estimates would all be increased by a constant percentage. The difference will therefore completely disappear in the second estimate.

TABLES BASED ON D. B. H. INSIDE OF BARK

There is a strong possibility that in some cases a volume table made in a certain locality will not be usable in a different locality because of a difference in the average thickness of the bark. This is particularly true when the volume given is inside the bark while the diameter measurement, the d. b. h., is outside the bark. There are, therefore, some advantages in preparing the alinement chart in such a form that d. b. h. inside of bark may be used as an alternative. If this is done the correction of the table to apply to a new locality may be simplified.

It is a simple matter to prepare a curve showing inside bark d. b. h. over outside bark d. b. h. for the basic data of the table. The readings of this curve can then be transferred to the diameter axis of the finished chart, marking d. b. h. inside of bark opposite the corresponding d. b. h. outside of bark on the final scale. This has been done in Figure 8.

It is equally possible to work from the beginning with diameters inside of bark, and then later enter additional graduations applying to diameters outside of bark. Somewhat better definition of the various curves is obtained if diameters inside bark are used. As a matter of fact, the chestnut table illustrated in Figure 3 was thus prepared, and the diameter graduations there given are for d. b. h. inside of bark. The d. b. h. graduating curve for outside of bark has been omitted for simplicity.

THE FORM OF BASE CHART FOR MERCHANTABLE VOLUME IN CUBIC FEET

It would be possible to use the base charts already described for volume tables giving the merchantable volume in cubic feet to some fixed standard of top utilization, such as 4 inches. It is preferable, however, to use a slightly different chart giving first-estimate volumes

which are a little closer to the actual measured volumes of the trees, and diameter-correction curves (such as those in Figure 6) which are more nearly straight lines.

The chart adopted by the Forest Service is based on the paraboloid. This is the simplest geometrical solid which is closely similar to a tree. The formula for the volume of a paraboloid is

$$V=\frac{BH}{2}$$

where V is the volume in cubic feet, B the area of the base in square feet, and H the height in feet. Allowing a stump height of 1 foot, the volume of the paraboloid above this is

$$V=\frac{BH'}{2}$$

$$\text{where } H'=H-1$$

If the unmerchantable portion of the tip of such a paraboloid is truncated, this volume will be reduced by

$$v=\frac{bh}{2}$$

where v is the volume of the unmerchantable tip, b the area of the tip at the point of truncation and h the length of the tip. The merchantable volume of the paraboloid is, therefore,

$$V-v=\frac{BH'}{2}-\frac{bh}{2}.$$

In a paraboloid, however, the taper in area is porportional to the length. It follows therefore that

$$\frac{h}{H'}=\frac{b}{B}$$

and that

$$h=\frac{bH'}{B}.$$

Substituting this value in the previous equation, we have

$$V-v=\frac{1}{2}\left(BH'-\frac{b^2H'}{B}\right)$$

or simplifying,

$$V-v=\frac{H'}{2}\frac{(B^2-b^2)}{B}.$$

This may now be expressed logarithmically as follows:

$$\log\,(V-v)=\log\frac{H'}{2}+\log\left(\frac{B^2-b^2}{B}\right)$$

$$\text{or } \log\,(V-v)=\log\left(\frac{H-1}{2}\right)+\log\left(\frac{B^2-b^2}{B}\right).$$

For any desired standard of top utilization, b, and therefore b^2, is a constant. It is a simple matter to prepare an alinement chart similar in form to that already described by means of which this formula may be solved. An example is shown in Figure 10. The graduating curve for V is a straight line, that for H is not quite straight because of the correction for stump height, while that for diameter is considerably lowered for the small diameters, because of the small differences between B^2 and b^2.

The base charts of this type, as used by the Forest Service, are for top utilization to 2, 3, 4, 5, and 6 inches.

It should be noted that there would have been no similar advantage in the use of the paraboloid rather than the cylinder in the case of the previous base chart for the volume of the entire stem. The volume of a paraboloid is one-half that of the cylinder of the same dimensions. The cylinder volumes multiplied by the form factor 0.40 would therefore be identical with the paraboloid volumes multiplied by 0.80.

It will be noted that the three sets of graduating curves on Figure 10 are designated D_p, H_p, and V_p, respectively. These are abbreviations for diameter of paraboloid, height of paraboloid, and volume of paraboloid.

After the proper base chart has been selected the procedure followed in preparing the volume table is in all respects identical with that already described.

THE FORM OF BASE CHART FOR MERCHANTABLE VOLUME IN BOARD FEET

The formula for the volume of a geometrical solid which resembles a tree in form and which is scaled in board feet by a log rule, is unfortunately very complex and not such as can be expressed accurately by an alinement chart. It has been found, however, that a fairly close approximation can be worked out. The process of preparing such an approximation chart is both tedious and involved and is difficult to describe. It consists in general of the following steps:

A series of values for volume are computed for some assumed solid, for a range of values of diameter and height. After experiments with several alternatives, the solid preferred is the cone frustum for tables to be related to merchantable height and the paraboloid for those related to total height. The solid is divided into 16-foot logs and scaled by whatever log rule is desired.

A base chart is then laid out with tentative parallel straight-line axes for diameter, height, and volume. The height and diameter axes are not graduated; that for volume is graduated logarithmically for several inches at the top. The graduations for the maximum diameter used and the maximum height are placed horizontally opposite that for the maximum volume. Lines through this maximum-diameter graduation and a series of three or four corresponding volumes intersect the height axis at corresponding heights, and fine pencil lines are drawn to record these indications of the positions of these height graduations. Similarly, starting from the maximum height, indications of two or three diameter graduations are obtained. Intersecting back from the second and third of these tentative diameter graduations will give a second and third series of intersections on the height axis, which should agree closely with the first. If they do,

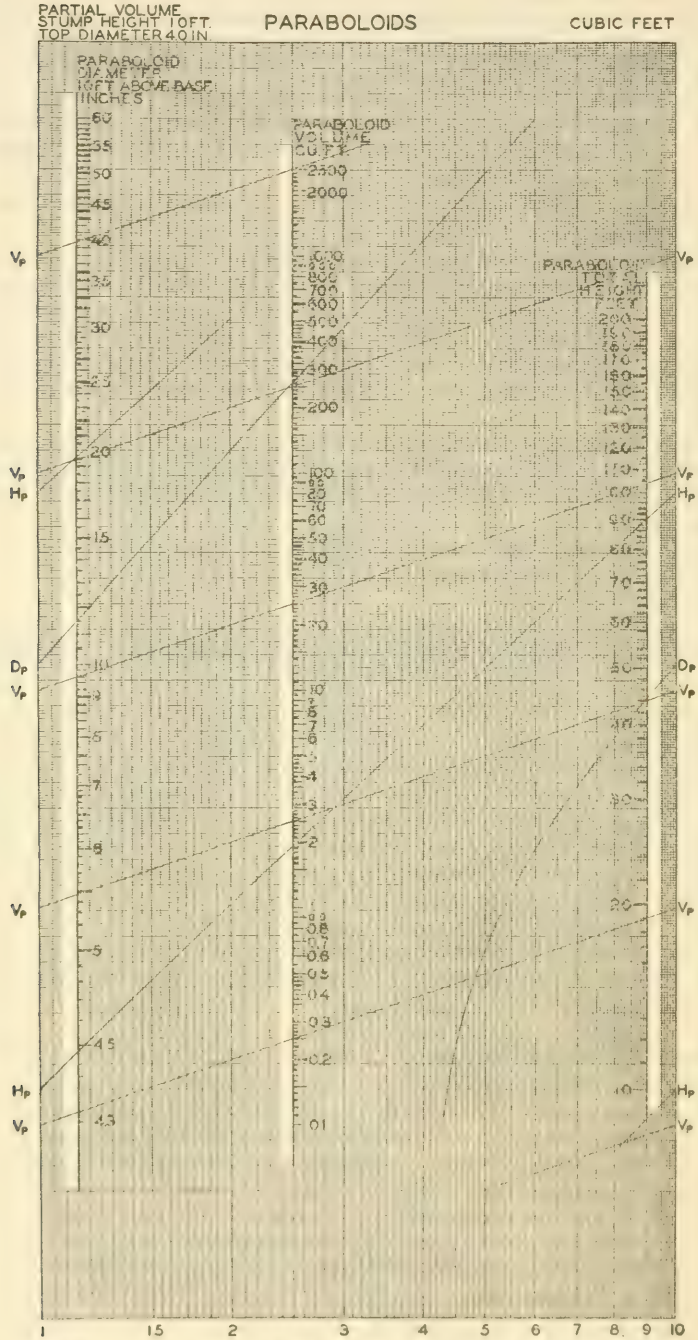

FIGURE 10.—Form of base chart used for volume tables giving merchantable volume to a 4-inch top, in cubic feet, based on diameter and total height

these height graduations are accepted. Reversing the process, the tentative graduations of the diameter axis are checked by other intersections. When this diameter axis has been carried a few inches, attention is again turned to the height axis, and so on alternately.

The intersections of lines from the larger diameters and heights will usually be well defined. Later, as smaller values of height are intersected back to the larger diameters, they may be found to fall above or below the previously established points. Similarly, lines from the smaller diameters may consistently intersect high or low. This is an indication that the lower part of the volume scale needs expansion (when the intersections are above) or contraction.

The correction of the volume scale is accomplished by locating new points on the volume graduating curve, which is done by laying the straightedge on the diameter and height and noting the intersection on the volume axis. This intersection is then projected horizontally to the ordinate representing the corresponding volume. For this correction the diameter and height points used are those established by the upper values, which have been confirmed by good intersections.

Sooner or later, the intersections may not fall on the original straight diameter and height axes and a curve must be substituted. If the intersections are well defined, the axes alone should be curved. If, however, the intersections fall, not around a point but along a line, such a multiple intersection usually indicates a simultaneous adjustment of volume scale and of one or both of the diameter and height axes.

The graduating curves are carried along simultaneously for all three axes. Each intersection located will fix a point on one of these graduating curves, but since the result being attained is only an approximation chart the points will not lie exactly on the curve, and a smoothing process has to be resorted to. The same thing is true of the axes themselves.

An example of the sort of chart finally produced by this process of trial and error is shown in Figure 11. It must be admitted that there is a large personal equation in the preparation of such a chart. Different workers might produce charts materially different in appearance. The test of their adequacy is whether the original basic values mentioned in step 1 can be reproduced with sufficient accuracy by means of the chart. This is true of the charts presented here.

A peculiarity of the chart illustrated in Figure 11 is the intersection of the lower ends of the volume and diameter axes. This is to be expected as a result of the scaling practice which neglects taper in 16-foot logs. All trees which are exactly one log in height to a 6-inch top will therefore have exactly the same scale regardless of their d. b. h. This condition can be met only by an alinement chart which has a common point for 16.3 feet on the height scale and 20 (the volume of a 6-inch, 16-foot log) on the volume scale.

It has been found, however, that this condition can not be met in all of the cone-frusta charts, particularly those based on the Scribner rule. The difficulty appears to be associated in part with the eccentricities of the rule itself, which does not follow any mathematical law. Accurate results at this one fixed point can only be obtained at the expense of material errors in adjacent diameter classes. An example

of the sort of compromise chart which has been adopted is illustrated in Figure 12.[12]

In base charts for board-foot volumes related to total height the peculiarity noted above (fig. 11) does not exist because merchantable length is not rigidly correlated with total height. The characteristic form of these total-height base charts is shown in Figure 13.

THE TECHNIC IN THE CASE OF THE BOARD-FOOT TABLES

The technic for board-foot tables follows, in general, exactly the same procedure as that followed in the cubic-foot tables already described, and only one or two details need be mentioned.

For reasons already discussed, the measured and first-estimated volumes in the tables related to merchantable height must be identical for a 1-log tree of the minimum top diameter used. This means that this volume determines a fixed point on the *measured—first estimate* curve, and this fixed point makes the fitting of this curve easier. The same thing is not true, of course, of the tables related to total height, in which the lower end of this curve is often ill defined. Near the minimum d. b. h. many of the trees will be so rapidly tapering that they will not contain a merchantable log and so will have a volume of zero. An average of a small number of trees, some of which have a zero volume, will naturally be erratic. This difficulty can be corrected only by obtaining a relatively large number of data for these very small sizes, which may not be practicable. At all events, moderate errors in the very small trees are usually of little moment.

The small trees also cause some difficulty in connection with the average percentage deviation. Since this deviation is expressed as a percentage, there are many cases near the minimum diameter where the percentage deviation of an individual tree will be either 100 per cent, when the basic solid has a volume and the tree itself has not, or infinity when the converse is true. An average including even a single infinity is, of course, itself infinite, and highly misleading. The most practicable plan seems to be to omit from the calculation of the average percentage deviation (but not from that of the aggregate difference) the entire diameter classes for which either the estimated or any of the measured volumes are zero. The expression of average percentage deviation should then include the minimum diameter used, together with the number of trees entering into the average percentage given, as:

Average percentage deviation (494 trees, 13 inches plus): 9.8 per cent.

[12] The series of charts in use by the Forest Service for board-foot volumes includes the following: (Based on merchantable height) Scribner rule, height and volume to 6-inch top, to 7-inch top, to 8-inch top, and to a 10-inch top; International rule, height and volume to 5-inch top, to 6-inch top, to 8-inch top, and to 10-inch top. (Based on total height) Scribner rule, volume to 6-inch top, to 8-inch top, and to 10-inch top; International rule, volume to 5-inch top, to 6-inch top, to 8-inch top, and to 10-inch top.

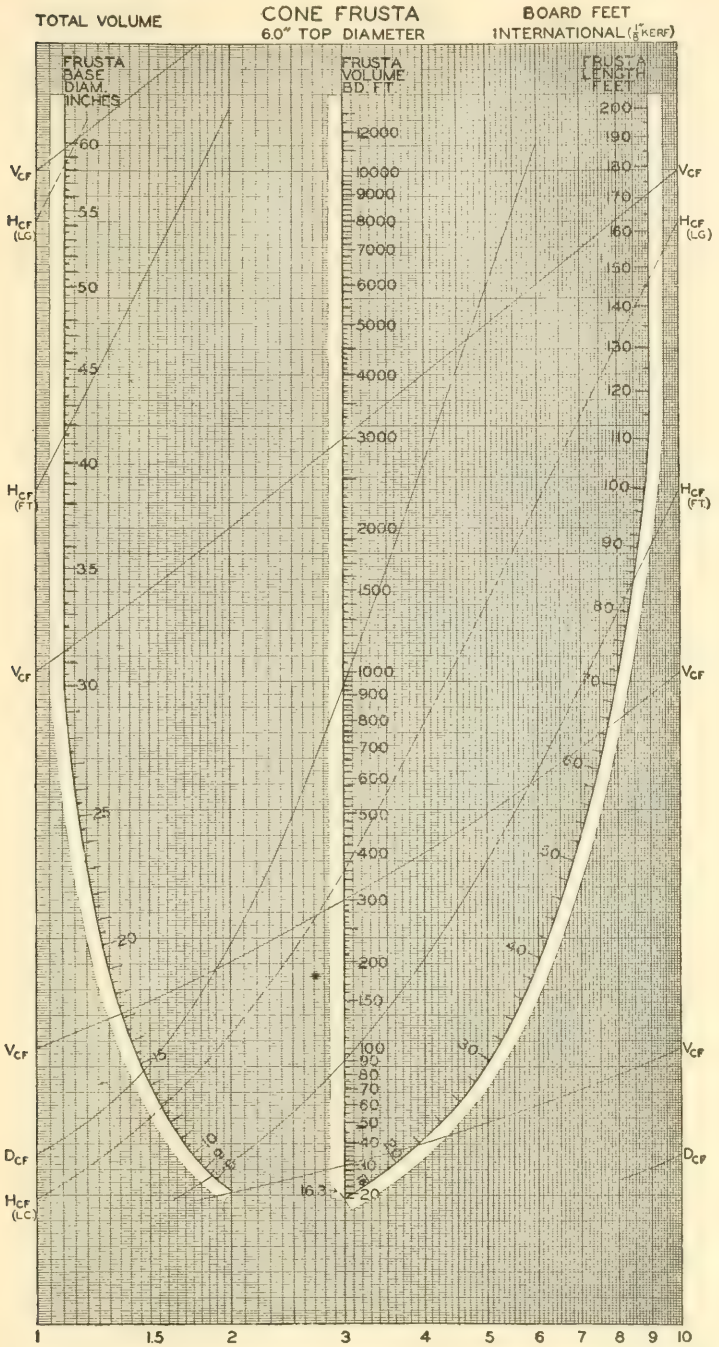

FIGURE 11.—Form of base chart used for volume tables giving total volume to a 6-inch top, in board feet by the International rule (⅛-inch kerf), based on diameter and used length. The curve $H_{CF(LG)}$ may be used to graduate the height axis in terms of 16.3-foot logs

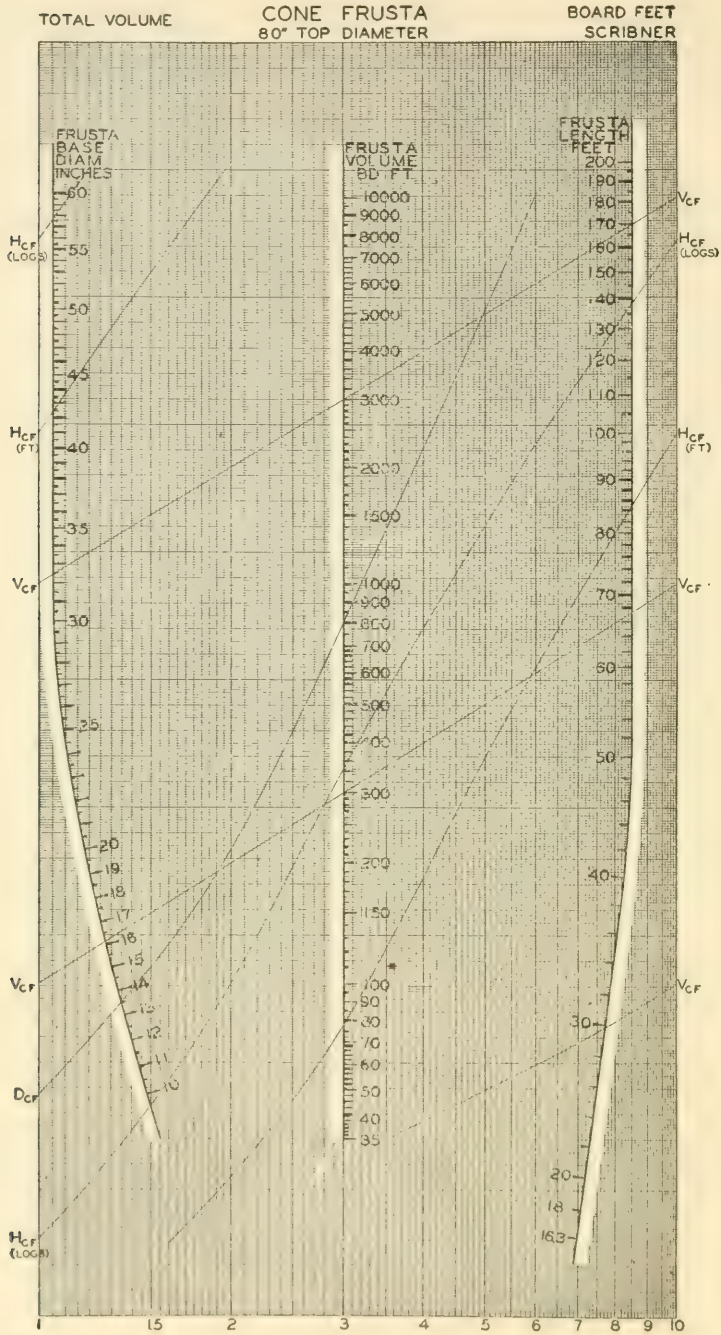

FIGURE 12.—Form of base chart used for volume tables giving merchantable volume to an 8-inch top, in board feet by Scribner rule, based on diameter and merchantable height. The curve $H_{CF(logs)}$ may be used to graduate the height axis in terms of 16.3-foot logs

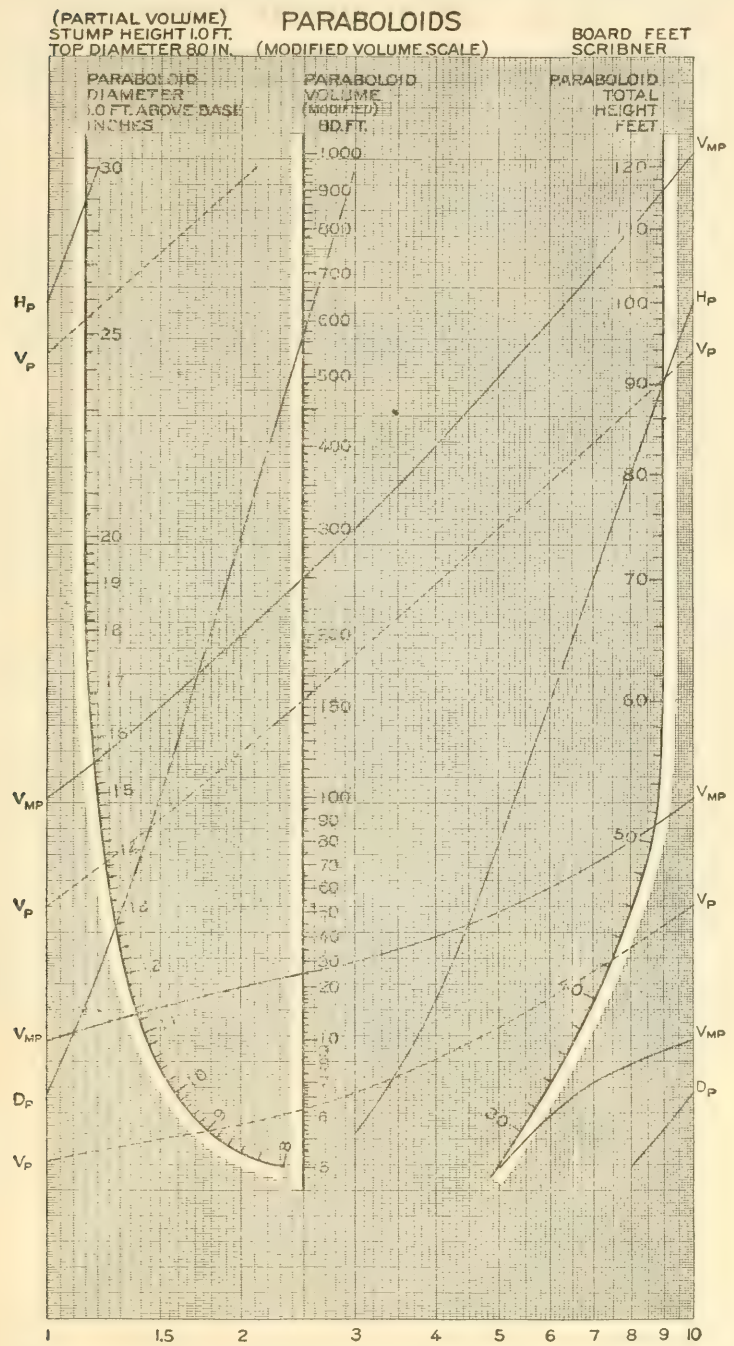

FIGURE 13.—Form of base chart used for volume tables giving merchantable volume to an 8-inch top, in board feet by Scribner rule, based on diameter and total height. The volume scale has been modified to agree more closely with the average form of trees. True paraboloid volumes may be obtained through the use of the V_p graduating curve

THE ADVANTAGES OF THE ALINEMENT-CHART METHOD

The advantages of the alinement-chart method can best be brought out by comparing it with alternative methods in use. The old-fashioned method of fitting harmonized curves was cumbersome and ineffective because the data available were distributed among a number of curves. As a result none of these curves was well defined unless an exceedingly large number of data were at hand. In contrast, each curve which must be fitted in the alinement-chart procedure is based on all the available data and is nearly straight-line in form. Furthermore, the weighting of the points in the case of the harmonized curves was exact only in the first stage; in cross curving it was customary to ignore the weights altogether, and impossible to assign weights in any satisfactory manner. Serious errors sometimes resulted. In contrast, in the new technic exact weights are available at every stage.

In comparison with the method based on frustum-form factors, the new method is more flexible in two respects. In the first place, it does not involve the implicit assumption that the frustum-form factor is correlated with diameter alone and is independent of height within a diameter class. As a matter of fact, it has been fairly well established that this assumption is false, especially in second growth; although for mature timber the errors involved in it are small. Tables produced by the alinement-chart procedure may show a partial correlation between form factor and height.

In the second place, the new procedure is applicable to any type of table, while the frustum-form factor method was restricted to tables of volume in board feet based on merchantable height.

The new method is almost self-checking. The aggregate difference is obtained by a mere addition of two columns of one of the work sheets, while the average percentage deviation involves a relatively small additional amount of labor, the measured and tabular or estimated values being already listed in parallel columns. This contrasts strongly with other methods, in which the calculation of these two measures of accuracy is excessively laborious.

As a result of these several advantages the alinement-chart method is a more efficient procedure. This efficiency may be utilized either by reducing the number of data required for a table of given accuracy or by increasing the accuracy obtained with a given number of data. In addition, time and labor will be saved through its use.

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ECONOMIC UTILIZATION OF MARGINAL LANDS IN NICHOLAS AND WEBSTER COUNTIES, W. VA.

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.
IN COOPERATION WITH THE AGRICULTURAL EXPERIMENT STATION OF WEST VIRGINIA

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In 1926 and 1927, A. J. Dadisman, of West Virginia University, recognizing the need for a study of land utilization conditions in that State, worked with Paul A. Eke, of that institution, in preparing the tentative outline of such a project. Later, an arrangement for a cooperative project was made with the United States Department of Agriculture.

Many of the agricultural and forestry phases of this investigation were planned and supervised respectively by L. C. Gray, in charge, Division of Land Economics, and W. N. Sparhawk, senior forest economist, United States Forest Service, both of the United States Department of Agriculture.

Thomas W. Skuce, extension forester, West Virginia University, J. S. Cotton, assistant economic analyst, Division of Land Economics, United States Department of Agriculture, and Lamar A. Wood assisted in gathering the field data.

Special acknowledgement is due F. J. Marschner, research assistant, Division of Land Economics, for his work in preparing the basic maps and for numerous suggestions relative to the preparation of the manuscript, and to Margaret A. Charters of that division for supervising the tabulation of the data.

The investigators wish to express their appreciation to the farmers of Nicholas and Webster Counties, the lumber companies, and the county officials for their courtesy in furnishing the information presented in this publication.

Before the manuscript was ready for publication, Millard Peck resigned from the service of the Department of Agriculture and Paul A. Eke left West Virginia University. In completing the manuscript it became necessary to make extensive changes for which the original authors are not responsible. The work of completing the portion of the manuscript that deals with agricultural utilization was done by O. M. Johnson, of the Division of Land Economics.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

ECONOMIC UTILIZATION OF MARGINAL LANDS IN NICHOLAS AND WEBSTER COUNTIES WEST VIRGINIA

By MILLARD PECK, *formerly Senior Agricultural Economist, Division of Land Economics, Bureau of Agricultural Economics,* and BERNARD FRANK, *Assistant Forest Economist, Office of Economics, Forest Service,* and PAUL A. EKE, *formerly Assistant Professor of Agricultural Economics, College of Agriculture, West Virginia University*

In cooperation with the Agricultural Experiment Station of West Virginia

CONTENTS

	Page
Introduction	1
Geographic characteristics and economic development of Nicholas and Webster Counties and the surrounding area	4
Economic development of Nicholas and Webster Counties	5
Economic organization of the section	7
Differentiation of farm and other land—agricultural phases of the problem	9
Relationship of soil type to farm economy	13
Soil type and crops	15
Soil type and livestock enterprises	17
Relationship of topography to farm economy	
Topography and crops	17
Topography and livestock	19
Combined effect of soil type, topography, and size of farm on farm income	20
The community as a factor in drawing the line between farm and other land	20
Forestry aspects of the land-utilization problem	25
The present situation	25
Changes in extent and character of forest resources	39
Trend and ownership	40
Possibilities of forest lands under management	40
Rates of growth of individual species	41
Growth of mixed, uneven-aged stands	42
Growth of even-aged old-field stands	43
Yields of saw timber	43
Combination of various products	47
Management of farm woodland	49
Costs of holding timberland	51
Outlines of an economic program for the Nicholas-Webster section	53
Economic program for farming	53
Public acquisition of scattered farms	54
Cost of government	54
Forest industries	55
Consolidation and management of farm woodlands	56
Consolidation and management of large tracts	57
Cutting policies	58
Protection from fire	59
Public assistance in private forestry	59
Public acquisition of forest land	60
The place of schools in the regional program	61
Roads in relation to regional planning	62
Extent of area in West Virginia to which results of this study probably apply	63
Literature cited	64

INTRODUCTION

Nicholas and Webster Counties are typical of a large area in West Virginia and other Appalachian States in which the most economic utilization of the land resources is a puzzling problem.[1] The first

[1] This study is the first of several projects having similar general objectives and now under way in Kentucky, Pennsylvania, and Vermont. Being the first study of this kind undertaken by the cooperating parties, and with but few precedents for the guidance of those planning the project, it is too much to expect that the results will serve as a model for projects of this type. In fact, it is characteristic of studies of this kind that they can not be completly standardized, but must conform in scope, emphasis, and method to the special conditions of the area studied. Nevertheless, the results of this study may be found helpful not only in the facts and conditions described, but also in suggesting methods to those conducting similar undertakings.

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objective of the investigation reported in this bulletin is to show which type of land should be used for agriculture and which for forestry and to try to point out the conditions that will determine whether land not easily classified as farm land or forest land should be used for a different type of farming or for a different combination of agriculture and forestry. The second objective is to indicate lines of improvement in the utilization of both farm and forest lands, and the relation of such changes in utilization to the social institutions of the area, particularly the schools and roads.

During the last half century agriculture in this area has been closely linked with the development of the forest industries which have furnished employment and local markets for surplus farm products. Most of the old-growth timber has now been cut, and the remainder can not last long. On some of the land farming no longer pays and as a result many fields once cultivated are now growing up to brush. At the same time the burden of carrying cut-over land is pressing heavily upon the owners. The problem of future land utilization in part of the area is therefore of urgent interest from both private and public standpoints.

Agricultural programs formulated in the past have for the most part been concerned with the better farming sections where the problem was to make a fairly profitable agriculture more profitable. This study is intended to aid in formulating a program of land utilization for those areas in which some of the land now farmed is so near the margin of economic use that it is doubtful whether farmers are justified in continuing to try to make a living on it.

Projects of this kind involve local agricultural forecasting and may properly be regarded as long-time outlook studies. In making such an agricultural forecast one is confronted with many uncertainties, and on that account the conclusions presented here are tentative and may need to be revised from time to time in the light of changing conditions.

The solution of the problem must be based on an analysis of the influence of purely physical factors, the most important being topography, type of soil, elevation, rainfall, drainage conditions, and the length of the growing season. It requires also an analysis of the economic possibilities of utilizing different kinds of land in different ways, including a consideration of the effect of changes in mode of utilization or community organization and of the possibility of modifying the conditions of land utilization through collective action, as for instance through changes in the amount, form, or incidence of the tax burden.

In developing a concrete plan for utilizing the resources of an area, it is assumed that an "optimum" relationship between the natural resources and the population to be supported is the goal. This relationship changes with time and circumstances. The optimum at a given time is attained only if the size of the population is so adjusted to the natural resources of an area as to afford standards of living comparable with those obtainable with similar human ability, exertion, and capital resources in other lines of activity or in other areas. In other words, the regional plan should seek to remove the effects of maladjustment of population to resources. If the population is excessive in view of the limited resources of the region, the plan should

show how the excess can be removed. In time, the adjustment will take place of its own accord, but if the maladjustment is anticipated certain forms of public action can be brought into play to expedite the readjustment.

The regional plan outlined in the following pages is premised also on the assumption that people will ultimately migrate from districts in which the return from the employment of labor and capital is persistently below that prevailing elsewhere for the same grades of labor and of capital goods.

Adjusting the costs of government to diminishing sources of revenue is another of the economic problems in this section. While the natural resources, on which revenue is closely dependent, have been diminishing, expenditures and taxes have been mounting.

In these two counties there are three general classes of land from the standpoint of prospective land utilization. (1) The most important area is that designated as agricultural land which furnishes occupation and income to the largest single group of gainfully employed in each county. No attempt has been made to work out a definite program for increasing income on this land except for cases in which a part of the land is devoted to timber production. The largest part of the cash income on agricultural land is from livestock, and it naturally follows that increased income to the farmers would come by the reorganization of live stock enterprises and the use of more economical methods of livestock production. The authors have made no attempt to discuss improved methods that should be followed in these two counties. Other investigators are at work on the problems of production on this kind of land. For example, the Division of Animal Husbandry of the United States Department of Agriculture and the West Virginia Agricultural Experiment Station have been conducting cooperative experiments on various phases of beef-cattle production in an adjoining county, Greenbrier. The West Virginia Agricultural Experiment Station is carrying on experiments in the production of pasture and feed crops. A publication is being prepared by the Division of Animal Husbandry and the Division of Farm Management, both of the United States Department of Agriculture, on "Beef Cattle Production, Problems in the Central Appalachian Region and Suggestions for Solving Them."

(2) The largest general class of land in these two counties has a forest cover of some kind and so far as can be seen now will always grow trees if anything at all. A conservative estimate of the proportion of the land that belongs in this class is 70 per cent. At present, approximately 85 per cent of the total area of the two counties has a forest cover of some kind. Some of this woodland will be cleared and converted into farm land, but the land best adapted to farming was cleared many years ago and the poorer parts of it will go back to timber. A program of forest and recreational use has been suggested for the nonagricultural land.

(3) A third general class of land, comprising about 10 per cent of the total area, has been designated as doubtful for agricultural use. This consists of isolated areas of productive land, areas of the poorer soils that are well located as to markets that may not be permanent, such as sawmill towns, and areas of unknown possibilities for agriculture.

GEOGRAPHIC CHARACTERISTICS AND ECONOMIC DEVELOPMENT OF NICHOLAS AND WEBSTER COUNTIES AND THE SURROUNDING AREA

Nicholas and Webster are contiguous counties in the east-central part of West Virginia, about 30 miles from the Virginia boundary. The surface of both counties is a deeply dissected plateau. Plate 1 shows that in the northern, northwestern, and eastern parts of Nicholas County and in most of Webster County the ridges have narrow crests and steep slopes. The valleys between are narrow and V shaped, the floors lying from 800 to 1,500 feet below the ridge tops.

In the central part of Nicholas and extending in a northeasterly-southwesterly direction entirely across the county and into Webster is a belt of land with smoother terrain, where the physical conditions are suited to successful farming.

Nicholas County, together with most of Webster County, lies in the watershed of the Kanawha River. The drainage is satisfactory except for about 25,000 acres of the broad-valley lands, that are found between the hills.

Weather conditions in this section are well suited to human habitation. The summers are pleasant, with cool nights and only occasional hot periods. The temperature varies with the elevation. On the higher ridges the winters are longer and more severe, and there is considerable snow. At Holcomb, in Nicholas County, with an elevation of 2,042 feet the average date of the last killing frost is May 15 and of the first, September 25. This gives the locality a growing season of about 4⅓ months. Killing frosts have occurred, however, as late as June 11 and as early as September 12 (*6*).[2]

The precipitation in the section is heavy, amounting to about 55 inches annually; it interferes with certain farming operations, especially at the higher elevations where fog often remains until late in the day.

The section has both residual and alluvial soils. The residual soils, derived from the weathering of interbedded sandstones and shales, are on the uplands, and their character is determined by the underlying rock. The alluvial soils are derived from materials washed down from the uplands and vary from very fine silt loams to sandy clay.[3]

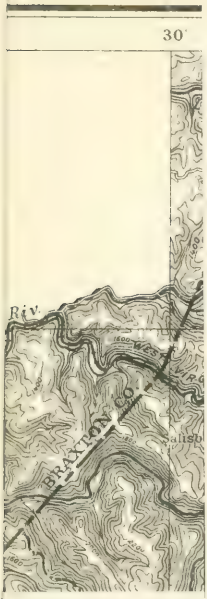
Both counties formerly were covered with an excellent stand of timber yielding from 12,000 to 20,000 board feet per acre. At present only 7 per cent of the area is covered with virgin timber. The more level areas such as the glades, the rolling lands, and the wider valley bottoms have been almost entirely cleared. Forest cover, however, including farm woodland, still occupies about 83 per cent of the total land area in Nicholas County and 89 per cent in Webster.

The original forest has been either culled or heavily cut over.[4] The few remaining tracts of virgin timber are located in the northwestern part of Nicholas County and in the eastern part of Webster County. These stands are now being exploited.

Italic numbers in parentheses refer to Literature Cited, p. 61.

[2] The reports on the soil surveys of both counties provided the basis for classification. The investigators gathered additional data on topography, stoniness, and drainage.

[3] Culling refers to the cutting in the original forest of scattered trees of the best quality of a few species; heavily cut over refers to the removal of all valuable trees down to at least 10 inches on the stump.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Lightly culled stands are likewise found in northern and northwestern Nicholas County and in the eastern part of Webster County. The rest of the uncleared acreage consists of stands cut over more intensively. Frequently the close cutting is followed by bad slash fires. There are some fairly large tracts of merchantable second-growth timber, but much of the timber is of poor character, because of careless logging methods and frequent forest fires.

There are small, scattered strips of old-field stands along the slopes of some of the valleys, in the cove heads, and on those ridge tops which have again reverted to forest after having been cleared and cropped.

The forest cover of the section, influenced as it is by differences in climate, elevation, and topography, is composed of a large variety of species.

Three types of forest vegetation are present. The lowest in elevation is the southern hardwood forest, which covers more than half of the State and extends into the western quarter of Nicholas County. It contains oak, chestnut, hickory, yellow poplar, maple, red gum, and walnut. Sassafras, redbud, and persimmon are also typical.

The rest of Nicholas County, excepting the extreme northeastern corner, and most of Webster County, are in the transition-hardwoods and hemlock forest, containing chestnut, oak, poplar, and hickory mixed with beech, maple, birch, and hemlock.

The eastern corner of Nicholas County and the southern and southwestern portions of Webster County, having over 3,000 feet elevation, are in the spruce and hemlock forest. Red spruce, hemlock, and yellow birch are the characteristic species.

ECONOMIC DEVELOPMENT OF NICHOLAS AND WEBSTER COUNTIES

Settlements in Nicholas and Webster Counties were first attempted shortly after the close of the Revolutionary War but were not permanently established until after 1800. "After 1795, settlers from Greenbrier and Kanawha began to occupy new lands in the region which in 1818 was formed into the new county of Nicholas" (*2, p. 32*).

Daniel Boone was in the region as early as 1774. According to Callahan, much of Boone's time, while he lived in the Kanawha Valley, was spent in locating and surveying lands. He was familiar with the geography and topography of the whole country. He had traveled and hunted, fought and trapped up and down all the streams and knew where all the good lands lay.

The first permanent settlement in Nicholas County was made near Lockwood, about 1802, by settlers from eastern Virginia. Later immigrants from Virginia and western Kentucky, seeking new hunting grounds, came in, and settlements sprang up along Peters Creek and Strouds Creek (*6*).

Webster County was formed from parts of Nicholas, Braxton, and Randolph Counties in 1860 (*2, p. 109*). The early settlers in Webster County came mostly from Virginia. Later settlers came from Pennsylvania and Maryland. The pioneers in both Nicholas and Webster were predominantly of Anglo-Saxon origin, and this stock occupies the land at the present time.

In Webster County the settlers usually located their homes along the narrow creek bottoms. In Nicholas County, on the other hand, some of the ridges are fairly broad, and the settlers established themselves on the ridge tops more often than along the streams.

The population of Nicholas County increased during every decade from 1820 to 1920, except the decade 1830 to 1840, and the population in Webster County increased in every decade following the county's organization up to 1920. The census of 1930 shows a very slight decrease for Nicholas County, but for Webster County a large increase amounting to approximately 23 per cent.

West Virginia counties are constituted of smaller subdivisions known as magisterial districts. In many respects these subdivisions serve the same purpose as do the townships in States farther north. In all the magisterial districts of Nicholas and Webster Counties the population increased steadily from 1870 to 1910. The census of 1930, however, showed that in 3 of the 11 districts the population had decreased after 1910, and in all the others, except Glade and Fork Lick in Webster County and Beaver in Nicholas County, the population had increased only slightly. Glade is one of the better farming districts and is likewise the center of important logging operations, which, however, are now rapidly moving eastward into Pocahontas County. The increase of population in Beaver district is due to the large labor demands of the mills located at Richwood. From 1920 to 1930 the districts containing Richwood City and the village of Summersville increased in population, but there was a decrease in the territory outside those places. Population declined considerably in two districts and remained approximately the same in three. In Webster County, one district had the same population in 1930 as in 1910, all the others showing a considerable increase.

According to the census, the area of land in farms in Nicholas County decreased during the 35 years prior to 1925. (Table 1.) In Webster County, on the other hand, during the same period the area in farms remained almost constant. Webster is a newer county and until very recently has been somewhat more isolated. For that reason its farm population has not felt so strongly the pull of the industrial centers. Moreover, it is the center of large logging and lumbering operations, which furnish winter employment and a market for farm produce.

TABLE 1.—*Land in farms, number and size of farms, Nicholas and Webster Counties, 1880–1930* [1]

Year	Land in farms		Number of farms		Average size of farms	
	Nicholas	Webster	Nicholas	Webster	Nicholas	Webster
	Acres	*Acres*			*Acres*	*Acres*
1880	192,532	99,340	1,115	502	172.7	197.9
1890	187,112	104,689	1,459	767	128.2	136.5
1900	192,227	115,786	1,767	1,058	108.8	109.4
1910	157,375	109,043	1,670	1,084	94.2	100.6
1920	153,726	99,184	1,670	981	92.1	101.1
1925	136,065	110,703	1,574	1,065	86.4	103.9
1930	148,307	93,609	1,800	1,104	82.4	84.8

[1] United States Census figures.

Apparently agriculture has almost, if not quite, reached the limit of its expansion in these two counties. The census of 1900 shows the maximum amount of land in farms at any period for Nicholas and

Webster Counties combined, while the report for 1930 shows only 79 more farms than at the beginning of the century. Some farms have been abandoned during the period and others consolidated, which would decrease the number, but some new farms have been established following the removal of the timber.

ECONOMIC ORGANIZATION OF THE SECTION

Farming, lumbering, and some mining constitute the principal industries of Nicholas and Webster Counties. There are also a few wood-using factories at Richwood, the principal city of the section.

These counties have four main types of roads: (1) Class A or State; (2) county; (3) improved district; and (4) unimproved district. Many of the unimproved district roads are nearly useless for the traffic requirements of the present day.

During recent years many miles of class A highways and improved district roads have been built in Nicholas and Webster Counties. The latter are usually built to substantially the same specifications as the State (class A) roads but are not hard surfaced. Their construction has increased the tax burden in several districts by as much as 40 mills to the dollar. As shown later, it is an expenditure that should be scrutinized with extreme care, for in many cases it is doubtful whether the natural resources of various districts are of sufficient value to warrant such highway improvements.

Telephonic communication among farmers in Nicholas and Webster Counties is almost entirely lacking, although on the better soils farmers are sufficiently numerous to carry whatever overhead expense would be involved in maintaining and operating a telephone system.

Local markets absorb much of the section's surplus farm produce. Generally speaking, West Virginia is deficient in food production, because of the relatively small acreage of farm land and the considerable progress of industrialization in the State.

Because the expense of transporting supplies in and out of central West Virginia is relatively high, local prices depend largely on local supply and local demand, neither of which varies greatly from year to year. Prices of farm products are therefore unusually uniform one year with another. Furthermore, as shown in Table 2, the prices of important farm products are higher in the West Virginia counties than in sections of surplus production. Although the prices in surplus-producing sections are for December 1 only, and those for the West Virginia counties represent prices received by farmers for sales throughout the year, the comparison indicates approximately the differences.

TABLE 2.—*Average farm prices of crops in 1926 in Nicholas and Webster Counties compared with average farm prices as of December 1 in main surplus-producing areas for the same year*

Product	Unit	Farm price, season of 1926, Nicholas and Webster Counties	Farm price, December 1, 1926, in surplus-producing areas
Corn	Bushel	$1.26	$0.56 (in Iowa).
Wheat	do	1.83	1.19 (in Kansas).
Oats	do	.82	.35 (in Iowa).
Buckwheat	do	1.33	.89 (in Pennsylvania).
Hay	Ton	15.11	14 (in Ohio).
Potatoes	Bushel	[1] 1.14	1.20 (in Wisconsin).[2]

[1] The price range during the fall of 1926 was $1 to $1.25 per bushel.

[2] In the fall months, prior to December 1, the farm price in Wisconsin had been reported at 25 to 30 cents per bushel.

Fat lambs and a considerable amount of poultry, particularly turkeys, are shipped to outside markets, mainly to Jersey City and Baltimore.

Credit facilities in the Nicholas-Webster section are apparently adequate, in view of the small degree of commercialism which characterizes the system of farming. The habit of borrowing for productive purposes has not become very prevalent, and little use is made of farm-credit institutions other than the local banks. In 1924, according to the Federal census, only 9 per cent of the farms reported mortgage indebtedness. Most of this credit was extended by private individuals.

The general property tax is chiefly relied upon for the raising of county and district revenue in this and the surrounding area. In spite of the fact that the State aids liberally in the support of the schools, they and the roads absorb about 85 per cent of the taxes raised locally. Table 3 shows in detail the purposes for which tax levies were made in four typical magisterial districts.

TABLE 3.—*Rate of levy on each $100 of assessed value in typical districts of Nicholas and Webster Counties for year ended June 30, 1928*

Purpose of levy	Nicholas County		Webster County	
	Wilderness district	Hamilton district	Fort Lick district	Hacker Valley district
General State expenditures	$0.10	$0.10	$0.10	$0.10
State of Virginia debt	.04	.04	.04	.04
Total State levy	.14	.14	.14	.14
General county expenditures	.30	.30	.30	.30
County roads	.25	.25	.25	.25
District roads	.15	.15	.15	.15
Roads; interest and sinking fund	.52½		.30	.30
Health officer			.03	.03
Special emergency district road levy	.10	.10		
Total levies by county court	1.32½	.80	1.03	1.03
Elementary teachers	.65	.55	.54	.64
Maintenance of school buildings	.15	.08	.15	.15
New school buildings	.20	.05	.20	.15
High-school teachers	.13	.13	.45	.05
Maintenance of high-school buildings	.02½	.02½	.06	
School interest and sinking fund	.02½	.02½	.05	
Total levies by board of education	1.18	.86	1.45	.99
Grand total all levies	2.64½	1.80	2.62	2.16

Although the maximum rates permitted by law have been levied for most purposes, deficits are common, particularly in the general county and the various school levies. The deficits are becoming more frequent on account of the declining value of agricultural, coal, and timber lands. To avoid them, expenses must be reduced, or assessments must be raised, or the legal rates of levy must be increased. Perhaps all these measures must be employed.

DIFFERENTIATION OF FARM AND OTHER LAND—AGRICULTURAL PHASES OF THE PROBLEM

A study of land as it is related to the income of farmers showed that there are considerable areas of certain land types in which practically all the farms have low incomes [5] and that there are other areas in which high incomes are generally obtained.

Incomes made by the farmers on poor, rough, stony, badly located lands were generally low as might be expected, whereas the incomes of the farmers on the better kinds of land were much higher. The land that returned low incomes is referred to as nonagricultural while the land that returned relatively high incomes is called agricultural land. Plate 1 shows the location of the agricultural and the nonagricultural land. An arbitrary satisfactory income that will be discussed later was selected as one measure of the adaptability of a land type to agriculture.

It was not assumed that all the farms on a land type should be abandoned whenever a large number of the farmers failed to make this satisfactory income. Many individuals would undoubtedly get a better income on this poor land than could be obtained in any alternative situation under existing conditions. Until society has provided a directing agency that will enable people to change occupations or location wisely, the greatest number can be given help in improving their conditions in their present environment rather than by suggesting a change. In spite of the fact that a low income land type may be occupied by a large number of people who can not find a better alternative, it must be recognized that from a social point of view there are problems on such land.

In some cases there may be partial abandonment, thus increasing the burden of maintaining adequate institutions and in other instances the people may remain on the poor land content with inadequate social institutions. No general solution to the problems on poor land types can be given, but they must be recognized and plans should be made looking toward the provision of a better living for the people who are handicapped by poor land.

Tenants' expenditures, rather than owners', have been adopted as the most appropriate measure of the standard of living used as a criterion to determine whether the land should be regarded as below or above the economic margin of utilization (Table 4), because of the fact that if a Nicholas or Webster County farmer should migrate to another agricultural section where the land is considerably above the margin he would probably go there as a tenant, for even though he might have owned a farm in Nicholas or Webster County it presumably would have been of low selling value.[6]

An income of approximately $1,200 would probably support a farm-living standard in West Virginia equivalent to the somewhat more expensive standards for the other States shown in Table 4.

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[5] For definition of income used, see p. 11.

[6] This statement is subject to some qualification. Some farms in this section are unsuited for profitable farming simply because they are too small. This is particularly true of the farms on Dekalb loam. Migration of a part of the population would permit consolidation of the small farms into larger ones. In this event the consolidating owner could afford to pay a price for land which, under the old order of things, was not yielding a reasonable return. As a matter of fact, land is frequently purchased for agricultural use, often at a high price, long after it has become submarginal for agricultural use. This is ordinarily because of misinformation, usually on the part of the unwary buyer. Moreover, the land, though submarginal for agricultural use, might still be supramarginal for forest use, in which case it would have some selling value.

Lumber is cheap, thus reducing the cost of housing. In central West Virginia the farm woodland furnishes a supply of fuel. Coal, too, is very cheap, many farmers having small mines on their own land.

TABLE 4.—*Tenants' standards of living as measured by the value of the various items of family living* [1]

Item of consumption	Kentucky [2]	Kentucky [3]	Ohio [4]	New York [5]	Missouri [6]	Iowa [7]	Kansas [8]	Average of totals
Number of farms	131	93	84	107	36	239	162	
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Food	556	594	564	818	769	600	592	642
Clothing	192	180	239	285	271	212	167	221
Furnishing and equipment	27	30	53	137	72	30	37	55
Operating expenses	155	155	198	134	260	216	168	184
Health	45	61	47	100	84	83	53	68
Advancement	38	53	49	319	122	72	65	103
Personal	23	11	52	24	64	25	40	34
Insurance	102	26	26		59	49	39	43
Unclassified	5		2	6			3	2
Total	1,143	1,110	1,230	1,823	1,701	1,287	1,164	1,351

[1] Value of shelter is not included among the items of family living, but value of food and fuel furnished by the farm is included, as well as items purchased. The aggregate values for the various surveys are adjusted to 1927 price levels, on the basis of the index numbers of prices of commodities used by farmers in family living. No modifications were made in the figures for 1922, 1923, and 1924, because the difference as compared with 1927 was so slight. The final average of totals is a simple average.

[2] NICHOLLS, W. D., and KIRKPATRICK, E. L. COST OF LIVING IN FARM HOMES, MASON COUNTY, KENTUCKY. A PRELIMINARY REPORT. U. S. Dept. Agr., Bur. Agr. Econ. 9 p. 1924. [Mimeographed.] Data for year ended June 30, 1923.

[3] KIRKPATRICK, E. L., and SANDERS, J. T. COST OF LIVING IN FARM HOMES IN SEVERAL AREAS OF KENTUCKY, TENNESSEE, AND TEXAS. A PRELIMINARY REPORT. U. S. Dept. Agr., Bur. Agr. Econ. 14 p. 1924. [Mimeographed.] Data for year ended Jan. 1, 1921. Data corrected to level of prices paid by farmers for commodities used in living, 1927.

[4] ——— and MELVIN, B. L. LIVING CONDITIONS AND COST OF LIVING IN FARM HOMES OF DELAWARE COUNTY, OHIO. A PRELIMINARY REPORT. U. S. Dept. Agr., Bur. Agr. Econ. 18 p. 1924. [Mimeographed.] Data for year ended Oct. 1, 1923.

[5] ——— ATWATER, H. W., and BAILEY, I. M. (*3*) Data for the year ended Sept. 1, 1921. Data corrected to level of prices paid by farmers for commodities used in living, 1927.

[6] ——— LIVING CONDITIONS AND COST OF LIVING IN FARM HOMES OF SELECTED LOCALITIES OF MISSOURI. A PRELIMINARY REPORT. U. S. Dept. Agr., Bur. Agr. Econ. 20 p. 1924. [Mimeographed.] Data for year ended Jan. 1, 1924.

[7] VON TUNGELN, G. H., THADEN, J. E., and KIRKPATRICK, E. L. (*9*). Data for year ended June 30, 1922.

[8] KIRKPATRICK, E. L., BURR, W., and BATCHELOR, E. M. LIVING CONDITIONS AND FAMILY LIVING IN FARM HOMES OF SELECTED LOCALITIES OF KANSAS. A PRELIMINARY REPORT. U. S. Dept. Agr., Bur. Agr. Econ. 21 p. 1925. [Mimeographed.] Data for year ended Dec. 31, 1923.

A schedule of expenditures which would need to have been made on the Nicholas and Webster County farms in 1928 to support standards of living equivalent to those found in supramarginal competitive agricultural sections is as follows:

Cost of living in Nicholas and Webster Counties, 1927 and 1928

Items of consumption	Cost
Food (purchased and home produced)	$628
Clothing	218
Furnishings and equipment	53
Operating expenses	93
Health	66
Unclassified	189
Total	1,247

People are bound by ties of sentiment and tradition to a section which has been their home for several generations. A considerable degree of inertia and friction is ordinarily involved in migrating from one place to another. It will therefore take a considerable difference of income to lead farmers to migrate. An allowance has been made

for these frictional elements, and in order to be conservative the necessary income for the West Virginia counties has been reduced from $1,247 to an even $1,200, of which approximately $450 is family living produced on the farm.

The competitive positions of the different kinds of land may be changed by a variation in the prices of the products; but since a smaller income in this section would in all probability be accompanied by a smaller income in other sections, it is likely that the greater part of the land classified as nonagricultural will continue to be in that category.

The average expenditures for living by tenants in the different States is composed of individual expenditures that vary greatly in amount. It is also true that there is a great range in incomes received by the farmers in Nicholas and Webster Counties.

In some localities in these two West Virginia Counties in which the average incomes were below the $1,200 standard of expenditures, there were many farms with incomes above the standard. It is to be expected also that a part of the Nicholas and Webster County farmers would be unable to get a better income in a supramarginal area in another part of that State or in some other part of the country.

The number of farmers who could improve their condition by moving would not be large at any given time. It is clear, however, that some of the land now in farms is not adapted to cultivation but should be used for grazing or the production of timber, both of which uses would furnish a livelihood for fewer families.

In considering the alternatives for these farm families, it must be recognized that the size of the family has an influence in determining what income is necessary to attract farmers to another section. The families in the Nicholas and Webster section average 7.2 persons, and the tenant families whose average expenditures were shown in Table 4 vary from 4 to 4.8 persons. The expenditure per person is, therefore, greater for the tenant families than for all families in these two West Virginia counties. Assuming that expenditure gives some indication of a standard of living, it appears probable that the estimate of $1,200 on the 1927 basis as an income necessary to hold farmers in Nicholas and Webster Counties is conservative. It would be materially lower in 1931.

In this study it was decided to employ, as an important indication of the suitability of land for farming, the net income obtained by farmers as a result of their farming operations plus such incidental returns from outside employments as seemed to fit into the farm economy. Data were obtained from 225 farms of various soil types and topographic conformations. A detailed income analysis for each of 174 of the farms was obtained. For the other cases, information bearing on various aspects of the farm economy was obtained, but the records were not sufficiently complete or the farm units themselves were not of such character as to permit or justify making an income analysis.

As a measure of the ability of an area to yield a return capable of maintaining a standard of living considered requisite to justify permanent occupancy, a concept of net income is employed which is designated operator's net income. In computing operator's net

income the ordinary running expenses, taxes, and interest on the investment in work stock, equipment, and buildings, and a charge for depreciation and upkeep on machinery and buildings other than dwellings, were deducted from the gross income, which included family living obtained in kind from the farm, and receipts from outside employment, gas leases, and other local sources of income. Interest was not charged on the "investment" in the bare land.

The investigators were concerned only in discovering whether the bare land, along with the operator's labor and the requisite buildings and equipment, would yield the net income, that (together with the incidental earnings obtained by the farmers from other employments) is sufficient to furnish the economic support for a standard of living which farmers obtain in competitive agricultural sections that are clearly above the margin of economic use.[7] Thus, the term "income" as here used includes "economic rent," or the earnings of the bare land wherever the land is above the margin. Since the investigators' concern was in locating the margin of agricultural use, the measuring of economic rent did not enter into the problem. Any earnings the farmer may have received from outside employment have been included in his income. This appears justifiable, first, because the income was probably not greatly in excess of what the farmer could have earned by confining his efforts entirely to his farm, and second, because a certain amount of outside employment fits into the farm organization and management practices of the section.

In studying the effects of soils and topography on income, the term "operator's land-labor income" has been employed, and is defined as the operator's net income minus the family living from the farm and income from outside employment. It seemed desirable to omit these items in studying the influence of the physical factors on income, although they are included when considering the question whether a particular locality yields a return that justifies its continued occupancy by farmers.

For short periods the income from the investment in buildings, equipment, and livestock is a quasi rent, rather than a necessary cost (*4, p. 74, 412, 420–421, 425–426, 577–579, 622–628*). This quasi rent is dependent upon the prices of farm products and the prices of cost goods entering into the economy of the farm. For short periods the farm revenue need not necessarily be sufficient to allow an interest and depreciation charge on this investment. For long periods, however, (and it is with a long period that this study is mainly concerned) the farm must yield a revenue adequate to cover a normal interest and depreciation charge on the investment in buildings and equipment. It goes without saying that the farm must in the long run also yield a return for the family labor equivalent to the return which laborers with the same grade of ability obtain in distinctly supermarginal agricultural sections, or the income which labor of the same grade or ability obtains in industrial employment.

[7] In some sections the investment in buildings is greater or less than would be requisite for efficient farm operation, but it is not believed that in the section under consideration such tendencies introduce serious complications.

In localities where the operator's net income for most farms is insufficient to support the standard of living that these people are likely to demand, it appears probable that ultimately the land will be abandoned, and will revert to brush and trees. Where the operator's net income now obtained by the farmers in this section is more than adequate to support the standard of living that is secured by people of the same grade of ability in agricultural sections clearly supermarginal or in industrial employment, the land probably will remain in agricultural use.

RELATIONSHIP OF SOIL TYPE TO FARM ECONOMY

Income and other aspects of the farm economy were classified with respect to four main soil types. These were the Dekalb and Atkins silt loams in combination,[8] Dekalb silt loam alone, Dekalb loam, and Dekalb stony silt loam. The acreage of each of the soil types in Nicholas and Webster Counties is shown in Table 5.

TABLE 5.—*Soil areas of Nicholas and Webster Counties* [1]

Soil type	Nicholas County	Webster County	Total	
Dekalb series:	*Acres*	*Acres*	*Acres*	*Per cent*
Dekalb stony silt loam	163,732	235,492	399,224	51.75
Dekalb silt loam	113,068	23,657	136,725	20.02
Total smooth phase	17,756		17,756	
Dekalb stony loam	73,306		73,306	9.50
Dekalb loam	18,577		18,577	2.41
Pope series:				
Pope sandy loam	9,319	7,504	16,823	2.18
Pope loam	1,012		1,012	.13
Pope silt loam	379		379	.05
Miscellaneous series:				
Atkins silt loam	3,233	1,209	4,442	.58
Lickdale silt loam	1,204		1,204	.16
Upshur silty clay loam	696		696	.09
Upshur stony silty clay loam		7,186	7,186	.93
Meigs clay loam	250		250	.03
Moshannon fine sandy loam		2,162	2,162	.28
Rough stony land	14,074	77,650	91,724	11.89
Total land area	416,606	354,860	771,466	100.00
Water area of the larger streams	1,194	1,293		

[1] The figures for the total area of the counties are the result of controlled mensuration on the United States Geological Survey quadrangle sheets, with the areas of quadrilaterals of 5 minutes' extent in latitude and longitude serving as control. The areas of the soil types are taken from the soil survey reports but are adjusted proportionately to the new figures of the total land areas.

Table 6 shows, by major soil types, the operator's land-labor income, the value of family living furnished by the farm, the income from outside employment, and the operator's net income. Family living furnished by the farm is largely a function of size of family. The farm having poor soil and rough topography and the size of which is limited by the physical features of the land returns an inadequate income, and greater reliance must accordingly be placed on income from outside employment.

[8] Atkins silt loam is an excellent bottom-land soil but is subject to overflow. It is always used in connection with Dekalb silt loam, an upland soil. Since no farms were on Atkins silt loam exclusively, it was necessary to consider the Atkins silt loam in connection with Dekalb silt loam.

The largest operator's land-labor incomes were more frequently found on the combination of Dekalb and Atkins silt loams. (Fig. 1.) The next largest incomes were found on the Dekalb loam and the Dekalb silt loam, which were nearly the same. These incomes, however, were due in part to the larger size of the farms in the latter group. The lowest average land-labor incomes from the farm prevailed on the Dekalb stony silt loam. The relationship between soil type and income can not be attributed to the influence of soil type alone. The other influences—topography, size of the farm, and the personal characteristics of the operator himself—must be considered.

FIGURE 1.—The broad-valley type of land. The soil in this instance is largely Atkins silt loam and is used chiefly for meadow or pasture

But, where soil and topography were both unfavorable, the operator's land-labor incomes were, with few exceptions, low regardless of the personal characteristics of the farmer.

TABLE 6.—*Incomes of farmers on soils of the major types, Nicholas and Webster Counties*

Soil type	Number of farms [1]	Value of family living furnished by the farm	Operator's land-labor income	Income from outside labor	Operator's net income
Dekalb and Atkins silt loams [2]	24	$471	$866	$276	$1,613
Dekalb loam	9	476	540	185	1,201
Dekalb silt loam	89	457	521	255	1,233
Dekalb stony silt loam	24	474	145	367	986
Miscellaneous	28	421	396	184	1,001

[1] In the two counties 225 farms were visited. Complete income data were obtained on 174. On 28 farms the soil types were so varied that they did not fall clearly within any one of the 4 soil classes. These are designated in the table as miscellaneous.

[2] See note regarding combination of Atkins silt loam with Dekalb silt loam, p. 13.

SOIL TYPE AND CROPS

To understand why small incomes are associated with certain types of soil it is necessary to examine the utilization of the various soil types for cropping, grazing, and forestry and the yields that are obtained from these uses. Table 7 shows the size of the farms associated with the four main soil types and the percentage of the land in each type devoted to crops, pasture, and woodland, respectively.

The Dekalb and Atkins combination is ordinarily associated with large farms in the broad valleys. The Atkins silt loam in the broad

FIGURE 2.—A valley farm surrounded by hills of moderate slopes, partly cleared. The field in the foreground adjoining the railroad is a typical poorly drained meadow

valley bottoms has always been used for growing hay and until recently has furnished winter feed for large numbers of cattle brought down from the surrounding uplands. (Fig. 2.)

TABLE 7.—*Average size, distribution of farm acreage among major uses, and operator's land-labor income per acre of cleared land, by major soil types*

Soil type	Number of farms	Size of farm	Cleared land, per farm	Operator's land-labor income from the farm per acre of cleared land [1]	Percentage of the cleared land—		Percentage of land in farms which is woodland
					In crops	In pasture	
		Acres	*Acres*	*Dollars*	*Per cent*	*Per cent*	*Per cent*
Dekalb and Atkins silt loam	24	227	163.3	5.30	36.7	63.3	27.3
Dekalb loam	9	89	55.6	9.71	52.6	47.4	36.0
Dekalb silt loam	89	130	74.8	6.97	47.0	53.0	41.7
Dekalb stony silt loam	24	116	53.8	2.70	34.9	65.1	53.2
Miscellaneous	28	167	76.7	5.16	44.3	55.7	53.4

[1] The most significant measure of the size of farm is the acres of cleared land per farm. The woodland is for the most part cut over and will yield no cash income for some time. The amount of pasture furnished by the woodland is negligible.

The Dekalb loam is excellent for cropping. It is an upland soil and is well drained. The early settlers quickly learned of its superior productiveness, and as the population grew, the farms were frequently subdivided until they now contain an average of only 89 acres. The operator's land-labor income from the farm per acre of cleared land on this soil is somewhat greater than that of the Dekalb silt loam, but because the farms are small the income per farm is only slightly greater than on the Dekalb silt loam, a soil inferior to the Dekalb loam. The low return per acre on the Dekalb and Atkins silt-loam combination does not reflect so great a difference in fertility in comparison with the Dekalb loam and Dekalb stony silt loam. It is, rather, due to the fact that so large a proportion of the cleared land on the Dekalb and Atkins silt-loam farms is devoted to pasture and meadow, much of it being too wet for cultivation.

The Dekalb loam and Dekalb stony loam soils are of light texture; during dry weather they quickly lose their moisture, which makes them unsatisfactory for pasture use. Their light texture, however, is advantageous for cropping, and on the Dekalb loam farms potatoes frequently yield as much as 300 bushels per acre. The stony character of the Dekalb stony loam makes it unsuited for cropping, and its light texture makes it unadapted to pasture use. Its productivity is therefore even lower than that of the Dekalb stony silt loam, and on this account it has been excluded from the zone of agricultural use.

The "rough stony land," of which there are 92,352 acres in the two counties, is distinctly inferior to the Dekalb stony and Dekalb stony silt loams and is therefore placed in the zone of forest use. This disposition of the land is also justified by the fact that it has never been occupied by farmers.

The yields and acreages of the principal crops grown on the farms included in this study are shown in Tables 8 and 9, respectively. Differences in the yields of corn, hay, potatoes, and orchard products are notable. The yields on the Dekalb loam farms are fairly high, but the acreage of each crop per farm is small, largely because of the rugged topography of the section.

TABLE 8.—*Normal*[1] *yields per acre of the principal crops*

Soil type	Corn	Oats	Hay	Wheat	Buckwheat	Potatoes	Apples
	Bushels	*Bushels*	*Tons*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
Dekalb and Atkins silt loam	42	28	1.1	16	28	144	52
Dekalb loam	37	27	1.1	16	27	138	56
Dekalb silt loam	36	28	.8	14	26	113	37
Dekalb stony silt loam	26	29	.8	15	25	95	25

[1] By "normal" is meant the yield which the farmer ordinarily expects.

TABLE 9.—*Average acreage per farm of the principal crops, 1927*

Soil type	Farms	Corn	Oats	Hay	Wheat	Buckwheat	Potatoes	Apples
	Number	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
Dekalb and Atkins silt loam	24	8.5	6.1	41.0	1.0	0.5	0.9	1.4
Dekalb loam	9	5.1	5.0	10.0	3.8	1.6	.9	1.2
Dekalb silt loam	89	6.1	5.8	17.5	1.0	1.1	1.1	1.6
Dekalb stony silt loam	24	4.1	1.9	11.3	.1		.6	.8

SOIL TYPE AND LIVESTOCK ENTERPRISES

Livestock is the chief source of cash income in the West Virginia Appalachians. Farmers of Nicholas and Webster Counties usually raise from 8 to 10 head of lambs and from 3 to 12 head of beef-type calves each year. The size of the livestock enterprises is generally limited by the ability of the farms to supply winter feed and pasture. The number of cattle and sheep per farm and per acre was largest on the combination of Dekalb and Atkins silt loams. This is partly because of the larger size of these farms and partly because of the large yield of hay per acre on the Atkins silt loam bottom lands. The light texture of the Dekalb loam makes it better adapted to the growing of cultivated crops than to grazing. In Table 7 it is shown that the percentage of cleared land in crops is greatest on the Dekalb loam. The crop surplus on the Dekalb loam farms is sold to the growers of livestock on those soil types not so well suited to cropping.

The Dekalb stony silt loam is not suitable for cropping and therefore does not supply the winter feed required for growing cattle. As sheep raising is less dependent than cattle raising upon the growing of forage for winter feed, there are more sheep and fewer cattle per farm and per acre on the Dekalb stony silt loam than on either the Dekalb loam or the Dekalb silt loam. Nevertheless the number of animal units per farm on the Dekalb stony silt loam farms is very small, and this in turn is reflected in low incomes.

TABLE 10.—*Number of livestock and cash receipts from livestock per farm and per acre on the major soil types*

Soil type	Farms	Total cows, heifers, and steers		Ewes		Total animal units, cattle and ewes		Cash receipts from all livestock	
		Per farm	Per acre of cleared land	Per farm	Per acre of cleared land	Per farm	Per acre of cleared land	Per farm	Per acre of cleared land
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Dollars*	*Dollars*
Dekalb and Atkins silt loam	24	20.2	0.12	16.6	0.10	22.5	0.14	1,262	7.73
Dekalb loam	9	5.0	.09	8.8	.16	6.2	.11	687	12.37
Dekalb silt loam	89	7.8	.10	10.7	.14	9.3	.12	684	9.15
Dekalb stony silt loam	24	3.0	.06	10.8	.20	4.5	.08	286	5.32

RELATIONSHIP OF TOPOGRAPHY TO FARM ECONOMY

Farmers' incomes in this section are not dependent on soil type alone. To repeat, income is mainly the resultant of four major influences: Soil type; topography; size of business; and the personal characteristics of the operator himself as they affect methods of management and the conduct of operations. These are not independent influences. They are closely interrelated; it is consequently impossible to measure precisely the net effect of any one.

On the basis of topography the farms can be described as follows: Gently rolling upland, broad-valley, narrow-ridge, and narrow-valley. Twelve broad valleys occur in Nicholas and Webster Counties. They are from ¼ mile to 2½ miles in width and 1 to 12 miles long. The bottom land is usually Atkins silt loam; the upland, Dekalb silt loam. The total area of the broad valleys is approximately 25,000 acres.

The gently rolling upland includes, generally speaking, the Dekalb loam, the smooth-phase Dekalb silt loam, and the very small areas of Lickdale silt loam soils.

The effect of topography upon the distribution of farm land among its various uses is shown in Table 11. The narrow-ridge and narrow-valley farms are small and have fewer acres of cleared land and crop and pasture land per farm than do the broad-valley farms. This explains in part their low income-producing capacity. Since the steep hillsides are not suited to growing cultivated crops, the narrow-valley farms have a relatively small percentage of their cleared acreage in crops and a large percentage in pasture. Because they are subject to overflow, the broad-valley farms also are characterized by a small percentage of cleared land in crops and a large percentage in pasture. (Fig. 2.)

TABLE 11.—*Major land uses on the principal kinds of topography*

Topography	Farms	Size of farm	Cleared land per farm	Crops per farm	Cleared land in crops	Cleared land in pasture	Woodland
	Number	*Acres*	*Acres*	*Acres*	*Per cent*	*Per cent*	*Per cent*
Broad valley	16	304	193.8	64.6	33	67	35
Gently rolling	45	148	93.6	45.7	49	51	36
Narrow ridge	56	121	60.4	29.9	50	50	49
Narrow valley	57	123	67.0	25.6	38	62	45

The narrow-ridge farms, like the narrow-valley farms, are small, partly because of the subdivision which is one of the consequences of the gradual increase of population in a more or less isolated section, and partly because of the difficulties of farm organization and management involved in operating a large farm on a long, narrow ridge. As the farms are inclined to be stony, hand cultivation is necessary, and it naturally follows that the extent of crop land per farm must be relatively small.

Table 12 shows that the gently rolling land was, generally speaking, the most remunerative at the time of this study. The apparent influence of size of farm on operator's land-labor income for a specific type of topography is marked. It is true, the variations shown in Table 12 are not in every case precisely what would be expected, but it should be remembered that in the cross tabulation the 174 farms are subdivided into 24 classes and subclasses. Part of this variation can be attributed to the personal characteristics of the farmer, but no measure of this type of influence on income is available.

TABLE 12.—*Relationship between topography, size of farm, and operator's land-labor income from the farm, 1926–1927* [1]

Topography	Less than 50 acres		50 to 99 acres		100 to 149 acres		150 to 199 acres		200 to 249 acres		Over 249 acres	
	Farms	Income	Farms	Income	Farms	Income	Farms	Income	Farms	Income	Farms	Income
	Number	*Dollars*	*Number*	*Dollars*	*Number*	*Dollars*	*Number*	*Dollars*	*Number*	*Dollars*	*Number*	*Dollars*
Gently rolling	10	478	22	529	8	1,379	2	564	1	1,677	2	1,684
Broad valley	1	316	5	495	3	988	2	802	—	—	5	1,052
Narrow ridge	27	300	23	307	2	328	4	952	—	—	—	—
Narrow valley	23	113	21	288	9	739	3	823	1	571	—	—
Total and average	61	260	71	416	22	968	11	819	2	1,124	7	1,232

[1] The data are for 174 farms.

TOPOGRAPHY AND CROPS

The relationship between topography and the acreage and yields of the principal farm crops is shown in Tables 13 and 14. The acreage of most of the crops is smallest on the narrow-ridge and narrow-valley farms. The fact that in the case of some crops the yields on the two poorest classes of land are not notably less than on the two best classes probably reflects in part the fact that ordinarily only the better-lying land on the narrow-ridge and narrow-valley farms is used for cropping purposes and perhaps only the better soils.

TABLE 13.—*Average acreage of principal crops per farm by topography, 1927* [1]

Topography	Corn	Oats	Hay	Wheat	Buckwheat	Potatoes	Orchard	Garden	Other crops
	Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
Broad valley	7.4	5.5	46.7	0.8	1.1	0.9	1.6	0.3	0.0
Gently rolling	7.8	7.1	20.2	2.2	2.1	1.8	1.0	.4	.8
Narrow ridge	4.6	4.6	15.3	1.2	.7	1.1	1.8	.4	.5
Narrow valley	5.4	3.8	13.1	.1	.5	.7	1.4	.3	.3

[1] The data are for 174 farms.

TABLE 14.—*Normal yields per acre of principal crops* [1]

Topography	Corn	Oats	Hay	Wheat	Buckwheat	Potatoes	Orchard	Garden, value per acre
	Bushels	*Bushels*	*Tons*	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Dollars*
Broad valley	38	25	1.1	11	27	140	61	258
Gently rolling	36	31	.9	14	25	138	57	316
Narrow ridge	38	27	.8	16	23	99	45	203
Narrow valley	30	27	.9	14	23	103	36	233

Based on data from 174 surveyed farms.

TOPOGRAPHY AND LIVESTOCK

A more pronounced relationship exists between topography and livestock operations than between topography and crop growing. Table 15 indicates that the numbers of both cattle and sheep are larger on the broad-valley and gently rolling farms than on the narrow-ridge and narrow-valley farms. The number of cattle per acre is also largest in the first two groups, but the number of sheep per acre is largest in the two latter groups. More feed is required to carry cattle through the winter than sheep. Since the acreage of crops is small on the narrow-ridge and narrow-valley farms it is more economical to raise sheep on farms of this type. On the other hand, the broad-valley farms produce a large quantity of hay, and for that reason their operators find it more economical to raise cattle. In the broad valleys the dampness of the ground is an obstacle to raising sheep, which thrive much better on the uplands than on the lowlands. Some consolidation of small farms will probably take place. This should make for more profitable livestock farming.

TABLE 15.—*Number of livestock on farms of the various topographic classes*

Topography	Farms reporting	Total cows, heifers, and steers		Ewes		Total animal units cattle and ewes		Cash receipts from livestock	
		Per farm	Per acre of cleared land	Per farm	Per acre of cleared land	Per farm	Per acre of cleared land	Per farm	Per acre of cleared land
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Dollars*	*Dollars*
Broad valley	15	20.7	0.11	15.3	0.08	22.9	0.12	1,361	7.02
Gently rolling	45	12.7	.14	13.8	.15	14.7	.16	931	9.94
Narrow ridge	56	5.2	.09	9.6	.16	6.6	.11	485	8.02
Narrow valley	57	5.1	.08	11.1	.17	6.7	.10	544	8.12

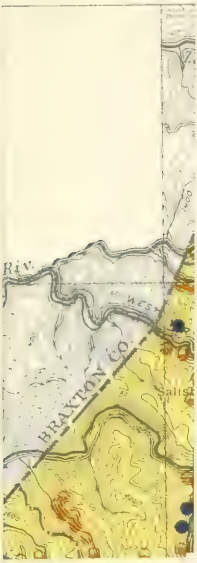
COMBINED EFFECT OF SOIL TYPE, TOPOGRAPHY, AND SIZE OF FARM ON FARM INCOME

The relationship of topography and size of farm was analyzed for the four most important soil types. A summary of this analysis is as follows: (1) On the Dekalb and Atkins silt-loam combination, 22 of 24 farms yielded a return of more than $1,200. These soils, therefore, appear to be adapted to reasonably successful farming. (2) The farms on the Dekalb loam are too small to return a satisfactory income but all of the land is agricultural and some consolidation of farms may be expected. (3) Only one of the 70 Dekalb silt loam farms containing less than 100 acres returned the minimum of $1,200. On the other hand 18 of the 19 farms containing 100 acres or more yielded incomes in excess of $1,200. It appears probable, therefore, that wherever topography permits tracts of Dekalb silt loam larger than 100 acres to be brought under single management, farming can be depended upon to continue indefinitely if the land lies in contiguous acreages large enough to support the necessary community institutions. (4) Only one of the Dekalb stony silt loam farms, regardless of size, yielded a satisfactory income. The Dekalb stony silt loam is always associated with the more rugged of the narrow-valley and narrow-ridge lands. There appears to be no type of farming suited to the utilization of the Dekalb stony silt loam soils. "Where fields of Dekalb stony silt loam are farmed longer than a few years or severely grazed they often become so eroded that they are practically valueless for agriculture and are abandoned or revert to forest. The forest growth should never have been removed entirely from much of the type that has been cleared." (*6, p. 16.*)

This soil type comprises approximately 52 per cent of the two counties. The Dekalb stony loam that constitutes about another 10 per cent of the area is of less value for farming.

THE COMMUNITY AS A FACTOR IN DRAWING THE LINE BETWEEN FARM AND OTHER LAND

So far the discussion mainly concerned the farmer as an individual, but another important aspect of the problem is the relationship of his farm to other farms in the community. The question is whether it is likely that this group of farms will in the future be able to produce enough to maintain a satisfactory community standard without a subsidy from outside.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In attempting to draw the line between farm land and other land and to determine institutional readjustments that appear desirable in connection with such a differentiation, a special study was made of the relation between the cost of supporting certain community institutions, particularly roads and schools, and the soil and topographic peculiarities of the section. These additional data in turn tend to confirm all the conclusions with respect to the distinction between farm and other land that had been drawn through considering merely the individual farm economy.

The first step in the study of the various communities was to locate each farm on a soil and topographic map, on the basis of information supplied by the district assessors. Plate 2 shows the location of the farms with respect to soil type and topography. It was found that the density of the farms and consequently of population, varied with soil and topographic conditions, being much less on poor than on good soils. Thirty-five per cent of all the farms in the two counties are located on soils on which incomes of less than $1,200 per farm can be expected. These soils constitute 73 per cent of the area of the two counties. On the other hand, 65 per cent of the farms are on land on which incomes of more than $1,200 per farm can be expected and which makes up the remaining 27 per cent of the total area. This difference in density of population makes the cost of schools and roads relatively high on the nonagricultural soils.

It was found that in certain small areas the soil and the lay of the land were satisfactory for farming, but there was not enough land of this character to provide a sufficient number of farms to support needed community institutions. In these more or less isolated communities the cost of financing schools and roads would now be more than the farmers could bear were they required to contribute all the cost or even a very substantial part of it. In such communities the largest part of the cost of maintaining schools and roads is borne by the nonagricultural land; that is to say, the timberland. Once the timber is removed, the financial support for the roads and schools will vanish, and the farmers will be forced to abandon their farms or get along with very inferior schools and roads.

Two areas that illustrate these conditions are upper Hamilton and lower Wilderness districts in Nicholas County. In reaching a decision as to the permanent agricultural possibilities of these two districts the determining factor was the cost of roads and schools per farm. In considering this cost the contributions from the county and the State have been included. Where the good land lies in small tracts and the farms are therefore scattered, the cost of maintaining schools and roads is so high that it would be cheaper for the State and county to buy the farms than to continue to maintain roads and schools.

In considering whether population in a particular area is sufficiently dense to justify the public in providing schools and other facilities and is likely to continue so, it is necessary to have in mind also those who make a living partly or wholly from nonagricultural occupations, and those who appear to be in various stages of gradually abandoning farming as an occupation. The farm residences of the section were therefore grouped according to type of use into six classes as follows: (A) Farms giving exclusive employment to operator; (B) farms operated throughout the year but operator working elsewhere during winters; (C) farms operated largely by family labor, but operator working

elsewhere most of the year; (D) farms used for garden and residence only; (E) farms operated in connection with an adjacent or neighboring farm; and (F) farms of which neither the land nor the buildings were being used. The number of each type is shown in Table 16.

TABLE 16.—*Number of farms on agricultural and nonagricultural land grouped according to the dependence of the farmers upon them for their living*

Class of land	Type of use						Total number of farms
	A	B	C	D	E	F	
Agricultural	596	145	375	320	137	171	1,744
Nonagricultural	172	69	290	255	50	122	958
Total	768	214	665	575	187	293	2,702

A = Farms giving exclusive employment to operator.
B = Farms operated all year but operator working out winters.
C = Farms operated largely by family labor, exclusive of head of family.
D = Farms used for garden and residence only.
E = Farms operated in connection with adjacent or neighboring farms.
F = Farms where neither land nor buildings are used.

TABLE 17.—*Percentage of farms on agricultural and nonagricultural land grouped according to the extent to which farmers depend upon them for their livelihood*

Class of land	Type of use [1]						Total
	A	B	C	D	E	F	
Agricultural	78	68	56	56	73	58	65
Nonagricultural	22	32	44	44	27	42	35
Total	100	100	100	100	100	100	100

[1] For definition of type of use (A–F) see Table 16.

TABLE 18.—*Number and percentage of farms by districts, land grouped according to the dependence of the farmers upon agriculture for their living*

District	Type of use [1]												Total	
	A		B		C		D		E		F			
Nicholas County:	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Beaver	82	29	20	7	67	23	69	24	35	12	13	5	286	100
Grant	72	44	14	9	26	16	27	16	8	5	16	10	163	100
Hamilton	66	22	38	13	80	27	49	17	12	4	49	17	294	100
Jefferson	39	27	10	7	24	16	43	30	9	6	20	14	145	100
Kentucky	118	35	23	7	59	18	73	22	11	3	51	15	335	100
Summerville	65	40	10	6	27	17	26	16	9	6	24	15	161	100
Wilderness	155	51	17	6	47	15	26	9	28	9	32	10	305	100
Webster County:														
Fork Lick	35	20	12	7	60	34	33	19	10	6	24	14	174	100
Glade	74	19	33	8	134	35	84	22	34	9	26	7	385	100
Hacker Valley	30	14	23	11	53	26	81	39	13	6	9	4	209	100
Holly	34	14	16	6	96	39	63	26	12	5	24	10	245	100
Total	770	28	216	8	673	25	574	21	181	7	288	11	2,702	100

[1] See Table 16 for definition of type of use.

Type A and type B farms, which took practically all the operators' time throughout the year, were more frequently found on the better soils. Forty-two per cent of the farms on the agricultural soils were of these types. On the nonagricultural soils, however, only 25 per cent of the farms were of the A and B type. The type C and type D farms, which are mainly country residences with some farming done by family labor, were found in greater proportion on the nonagricultural soils. These two types made up 57 per cent of the farms on the nonagricultural soils, whereas they constituted only 40 per cent of the farms on the agricultural soils. The fact that the type A and type B farms are more often associated with the better soils, and the type C and type D farms with the poorer soils, is another indication that the latter are less productive and that greater dependence must be placed upon outside labor to maintain such standards of living as the people of the section insist upon.

The percentage of abandoned farms was not much greater on the nonagricultural soils than on the agricultural soils for two reasons. In the first place a considerable extent of the soil which has been designated here as being suitable for agricultural use is associated with a type of topography unsuited to agriculture. In the second place, lumbering operations are found in localities close to the rougher land and poorer soils. On this account, farms that would otherwise be abandoned are now in use, but mainly for residential purposes.

An analysis showed that the cost per farm of maintaining roads and schools for the widely scattered communities is very high. In 9 of the 11 districts the tax on the farms was scarcely enough to cover the cost of building and maintenance of roads; therefore, taxpayers other than farmers paid the entire cost of running the schools. These scattered, isolated communities are usually in the midst of large timbered tracts and derive the financial support for their roads and schools from the timbered lands. As the timber resources become depleted the farms will have to absorb this cost. It is obvious that they can not do so permanently, and unless large appropriations of State aid are made the schools and roads must deteriorate. This in turn will hasten farm abandonment, for people will not live permanently where the schools and roads are inferior to those that they now have.

Table 19 shows the cost to all taxpayers of maintaining roads and schools in the various districts of Nicholas and Webster Counties. The third column shows the total cost of providing these services for the individual farms. The fourth column shows that part of the cost paid by the farms themselves. The remainder of the cost, shown in the last column, is the amount paid per farm by taxpayers other than farmers, mainly owners of timber land.

TABLE 19.—*Average cost per occupied farm to all taxpayers and to taxpayers other than farmers, for roads and 1-room schools, and average taxes paid by occupied farms in the various districts of Nicholas and Webster Counties, 1927–28*

District	Average cost to all taxpayers per occupied farm			Average real-estate tax paid by farmers per occupied farm	Average cost to taxpayers other than farmers, per occupied farm
	For 1-room schools	For county and district roads [1]	Total		
Nicholas County:	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Beaver	60	113	173	40	133
Grant	62	33	95	32	63
Hamilton	65	58	123	45	78
Jefferson	89	66	155	25	130
Kentucky	80	30	110	26	84
Summersville	81	56	140	41	99
Wilderness	71	24	95	35	60
Webster County:					
Fork Lick	160	108	268	44	224
Glade	93	62	155	34	121
Hacker Valley	81	25	106	40	66
Holly	66	28	94	20	74

[1] Levies for highway bonds were omitted because nearly all of these funds have been used to build trunk and State roads between the towns.

The maintenance of the country roads and rural schools of Nicholas and Webster Counties costs taxpayers other than the farmers from $53 to $223 per occupied farm. That is to say, for each of the farms in the various school districts there was required from $53 to $223 of outside money to support the schools and roads. If funds were borrowed at 4½ per cent interest and the present taxes were used in paying the interest on these funds, it would be economical to buy these farms, paying as much as from $1,316 to $4,954 for each, in order to eliminate the cost of maintaining roads and schools. According to the 1925 Census of Agriculture (*9*), the average value of farms in Nicholas County was $2,993, and in Webster $3,062. In certain of the magisterial districts where the land is universally inferior for agricultural purposes all the farms could be purchased for much less than the capitalized value of the existing taxes that the taxpayers other than farmers are now paying to maintain schools, roads, and other institutions.

In the two counties there are 74 schools in the nonagricultural districts. In 45 school communities out of 116 in the two counties, eight or fewer occupied farms lay within the territory from which the schools drew their patrons. With an average of approximately five occupied farms per school, the average cost of these schools in Webster County ranged from $156 to $245 per occupied farm. The latter amount would pay the interest at 4½ per cent on $5,444 worth of bonds, which would provide sufficient funds to buy all the farms in the territory patronizing these schools, at the average census value for the county in 1925, and would leave a balance of $2,382 per farm. In Nicholas County the average cost of maintaining small 1-room schools in 12 selected communities was $184 per occupied farm. This sum would pay the interest on a fund of $4,088, which would leave a balance of $1,095 for each farm above the average census value of farms of the county in 1925. These farms could probably be bought for less than the average value of farms for the county as a whole, and the saving would be still greater.

It is significant that 78 per cent of the 45 rural school communities mentioned were located on soils designated as being nonagricultural, and the remainder were located on agricultural soils of steep or narrow topography. This fact, considered in connection with the high cost of schools per occupied farm, confirms the validity of excluding certain soil types and certain kinds of topography from the zone of agricultural use.

FORESTRY ASPECTS OF THE LAND-UTILIZATION PROBLEM

THE PRESENT SITUATION

REMOVAL OF OLD-GROWTH TIMBER

The old-growth timber (fig. 3) in central West Virginia seems destined to be removed completely within the next 15 to 20 years. If the rate of cutting that prevailed in 1927 should continue, the section

FIGURE 3.—Most of the rugged area of Nicholas and Webster Counties is still covered with timber. The valley of the Elk River from Webster Springs eastward contains one of the largest single tracts of virgin hardwoods in the East

would be entirely divested of its large tracts of virgin timber in 10 years and of its lightly culled timber in 18 years. It is not likely that the large band mills will afterwards turn to the second-growth timber. Cutting in this class of forest probably will not be materially increased, within the next 20 years at least, over the present rate. If this assumption is correct and if fires are kept within reasonable bounds, the forest at the end of the next 20 years, including the growth made in the meantime, may contain a total volume of around 1,750,000,000 feet board measure or about 6,700,000 cords of timber covering about 692,000 acres. This will consist largely of second growth, with small scattered remnants of the old-growth forest, mostly on farms or in very inaccessible locations. These stands, together with the mer-

chantable second growth, wherever accessible, will be exploited mainly by portable sawmills.

EFFECT ON FOREST INDUSTRIES

The existing wood-using plants, including the pulp and paper mills, depend entirely upon the native supplies of old-growth timber. With the possible exception of the pulp mill they are all bound to disappear with, or shortly after, the band mills, or they will be withdrawn when the supply of large-size timber is gone.

It seems likely that the second-growth forests should afford an ample supply of timber at least for the secondary wood-working plants, which now consume in the aggregate slightly over 17,400,000 board feet annually. But even if the desired species (beech and maple) were present in the larger sizes suitable for veneer and handle stock, which is not likely to be the case, their scattered distribution among the many other species would alone prohibit their removal at a profit.

The plants utilizing hardwoods may continue operation for several years after the larger sawmills close down, by purchasing logs from farmers and from other owners of small tracts. Because of the small number of species that they can use, however, and because of the limited distribution of those species, they probably will not obtain a supply sufficient to warrant indefinite operation.

Second-growth forests will not yield sufficient spruce and hardwood to supply the pulp mill: its life can be extended beyond the 20-year period only by importing pulpwood, or by changing its equipment so as to utilize hardwoods. Whether the soda process would be commercially feasible for the many species available, particularly those of dark color, is open to question. The semichemical process, which is cheaper and more efficient in utilizing hardwoods, might be employed. The outlook for a continuation, possibly permanently, of pulp and paper manufacture is somewhat encouraging, in view of the ample quantity of available raw material and the short rotations required to grow trees of the requisite sizes.

On this situation hinges the continued operation of the Richwood branch railroad after the next 15 to 20 years. It is hardly likely, considering the nature of the products now being hauled out of the section and the limited possibilities for expansion of the coal industry, that sufficient tonnage would be available to justify a continuation of this line if all the large wood-working plants should cease their operations.

Such forest products as lumber and ties formed from 83 to 91 per cent of the total annual freight tonnage shipped from the section during the years 1922 to 1927. Other products derived from the forests, such as paper, wooden dishes, and clothespins, constituted an additional 6 to 11 per cent, and all forest products combined averaged 97 per cent of total shipments during those years. (Fig. 4.)

The products of agriculture alone certainly can not furnish sufficient tonnage, and it is doubtful whether the cut-over lands under present conditions will furnish material other than hardwood pulpwood sufficient to warrant continued operation.

EFFECT ON AGRICULTURE

While they lasted, the forest industries afforded important local markets for farm produce and an opportunity for employment which was needed to supplement the small farm incomes. The poorly

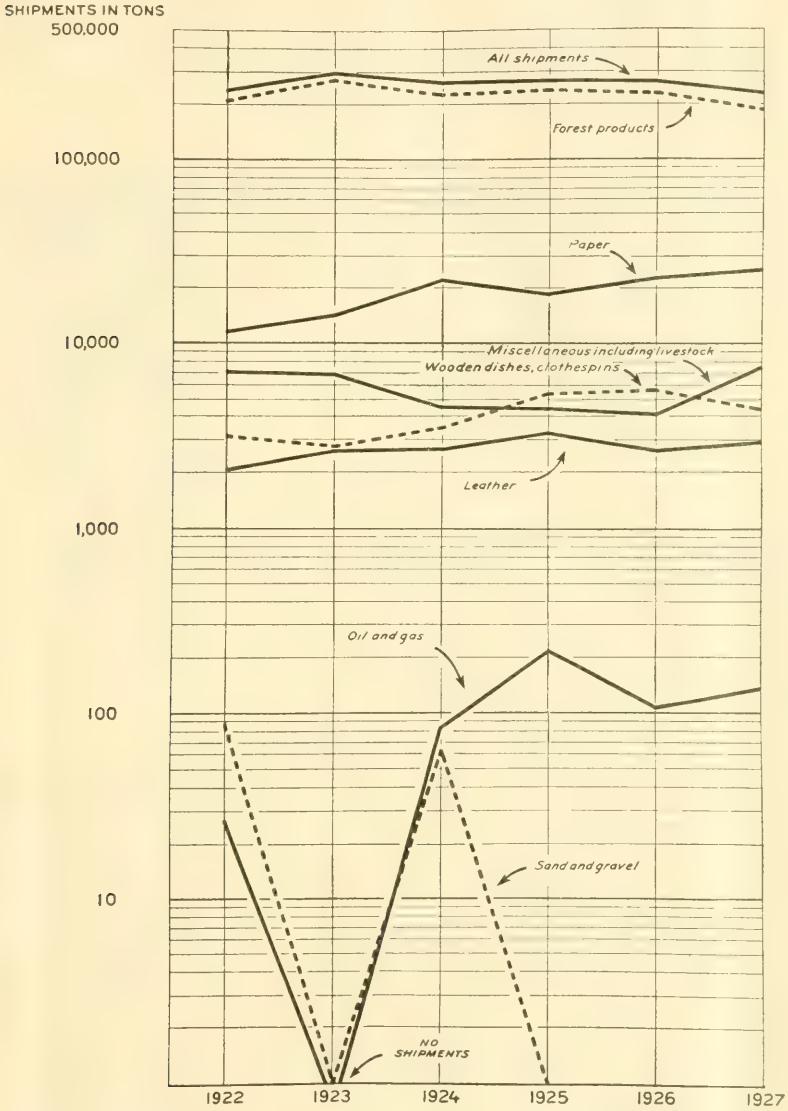

FIGURE 4.—SHIPMENTS FROM NICHOLAS-WEBSTER TERRITORY BY BALTIMORE & OHIO RAILROAD, 1922–1927

There is a slight trend downward of all shipments, and no products seem to be replacing those of the forest in importance.

stocked second-growth forests can not be expected to support industries on anywhere near so large a scale as those based upon the original stand. Only when effectively protected from fire and placed under

management will they ever give employment on any considerable scale.

Most of the farmers on the poorer soils are receiving inadequate incomes even with returns from outside employment amounting to about $300 a year. With the passing of the old-growth forests it will be difficult to maintain the present standard of living. Aside from the individual suffering, communities with persistently low incomes and consequently low standards of living constitute a threat to the standards of other communities more fortunately situated.

PRESENT FOREST COVER

The present forest cover including farm woodland and abandoned fields, either grown up or in the process of restocking, occupies roughly 664,000 acres, or 86 per cent of the entire land area of Nicholas and Webster Counties. Its distribution by classes of timberland is shown in Plate 3. The area of each class, including old fields, is given in Table 20. Various factors have influenced the development of many of the present characteristics of the forest cover.

TABLE 20.—*Distribution of forest areas by classes* [1]

Class of forest	Area in Nicholas County		Area in Webster County		Total area	
	Acres	*Per cent*	*Acres*	*Per cent*	*Acres*	*Per cent*
Virgin	11,200	3	34,900	11	46,100	7
Lightly culled	31,400	9	41,300	13	72,700	11
Merchantable second growth	104,100	30	60,000	19	164,100	25
Nonmerchantable cut over	181,500	53	171,500	54	353,000	53
Old field	18,800	5	9,500	3	28,300	4
Total	347,000	100	317,200	100	664,200	100

[1] Determined on the basis of information obtained from county officials, from maps of the larger holdings, from field observation, and from sample plots scattered throughout the section.

DEVELOPMENT OF LUMBERING

Much has been written concerning the early logging operations in West Virginia (*1*). In the section studied, the first cuttings, beginning as early as 1870, were strictly of a selective nature and included only the largest and best trees of a few species, because of the existing demand for but relatively few kinds of wood, and also because of the limitations of water transportation, used exclusively at that time to get the logs to the sawmills. Yellow poplar (*Liriodendron tulipifera*), black walnut, basswood, and later, spruce and hemlock were the species chiefly selected. During this period large numbers of logs were lost along the banks of the streams, for no attempts to salvage them were made.

Later, when mills were established closer to the forest and pole roads were built along the smaller streams, selected oak and chestnut trees were also taken.

After railroads were built into the territory, beginning in 1892, the more efficient railroad transportation rapidly replaced the wasteful "driftings" of logs. By 1910, 11 band mills in Nicholas County and 2 outside were cutting over 200,000,000 board feet annually, and in Webster County 4 band mills and 15 smaller scattered portables were in operation.

30'
Riv.
FRAXTON Co.

As the more intensive phase of lumbering developed, the possibilities of manufacturing products other than lumber were recognized and a large tannery, a pulp and paper mill, a woodenware plant, and a dowel and handle factory were established in Richwood, together with a softwood band mill. As a result, Richwood has become the center of the wood-using industry of the section.

The number of band mills has decreased since 1910 because of depletion of the timber. To-day there are four band mills in Nicholas County and four in Webster County.

EFFECT OF TYPE OF CUTTING ON FOREST COVER

VIRGIN STANDS

Nearly all the old-growth stands owned by farmers have been lightly cut into for domestic use. In other respects their character is no different from that of the large virgin tracts, except that they have received slightly better protection from fire. The volume of these stands runs from 12,000 to 25,000 board feet per acre, depending upon site, species, and severity of previous fire damage. Most of the volume is in the diameters [9] ranging from 12 to 24 inches, although these diameter classes contain only a small proportion of the total number of trees.

Severe suppression of the smaller trees (4 to 12 inches) is characteristic of old-growth stands. Suppression may be complete, preventing satisfactory growth of these smaller trees which, normally, would be growing the more rapidly.[10] Since the largest trees have passed their prime, disease and decay offset or even exceed the growth.

LIGHTLY CULLED STANDS

Lightly culled old growth (fig. 5) is characterized by the removal of large select trees of the best species. This practice leaves openings in which young trees, if present, find space for more rapid growth. If there is no young growth, new reproduction becomes established before the crowns of the remaining trees extend to close the openings. Most of the trees in these stands are still under 12 inches in diameter.

STANDS CUT TO DIAMETER LIMIT

After about 1900, operators began cutting to a rough diameter limit and utilized a wider range of species. The limit has varied from 18 inches to 12 inches, but in the earlier operations trees under 16 inches on the stump were not usually taken. This method of cutting left the stands in relatively good condition and with volumes averaging from 5,000 to 6,000 board feet per acre. Stands cut in this way from 6 to 25 years ago are now being cut over again.

STANDS HEAVILY CUT OVER

The present intensive phase of lumbering leaves principally those stands classed here as "heavily cut over" or "nonmerchantable

[9] Diameters of standing trees are measured at a height 4.5 feet from the ground, designated as breast height. This is usually written d. b. h.

[10] The individual trees may be divided into classes on the basis of the relative freedom of their crowns from shade. The collective term "dominant and codominant" is used to denote the fact that all or most of the crown is free of shade. Such trees are relatively of average size and larger. The term "intermediate and suppressed" indicates that most or all of the crown is shaded by taller trees. These terms apply to trees with straight, sound stems. Injured, deformed, or diseased trees, irrespective of their crown positions, are classed as "defective."

cut over." This is especially the case in stands either previously culled or cut to a diameter limit. Seventy-five to ninety per cent of the trees left are 10 inches or less in diameter, and the total residual volume is seldom over 2,000 to 4,000 feet per acre. From one-third to one-half of the remaining trees are defective. This large percentage of defect and decay in the small trees materially affects the ability of the stand to utilize the productive capacity of site. All stages of lumbering have been marked by removal of the most valuable and rapidly growing species. The remaining inferior species and defective trees have reseeded the ground and prevented adequate reproduction of the more valuable species. The slash left on the ground increases the danger of fire, which in many instances has completely destroyed such desirable second growth as had become established.

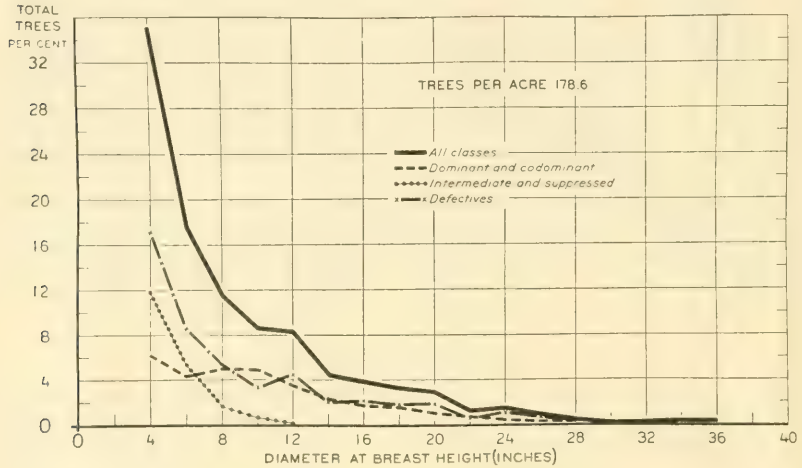

FIGURE 5.—STEM DISTRIBUTION IN LIGHTLY CULLED STANDS BY TREE CLASSES: OAK-CHESTNUT-HICKORY TYPE

The young trees of the dominant and codominant classes 4 to 12 inches in diameter have room to grow in the lightly culled stands.

EFFECTS OF FIRE ON THE FOREST COVER

As in all other sections of the southern Appalachians, fires have swept through the forests repeatedly. The greater part of the decay and the injury due to "timber worms" found in the older stands is the aftermath of earlier fire scarring. Fires have also impaired the fertility of the soil by burning the humus. This, along with the effects of scarring, has hastened decay and death of the timber.

The common butt rot, which is only one of the consequences of forest fires, renders valueless that part of the tree that contains the highest grade of lumber. Furthermore, the dead wood resulting from one fire furnishes excellent fuel for the next, and repeated burnings so weaken the trees that many of them are broken off by the wind.

Besides directly damaging the mature timber, fire greatly reduces the vigor of the forest. Although a large quantity of reproduction may follow even a severe fire, its quality is seriously impaired. Instead of seedlings, the new growth consists of sprouts, largely of

inferior species. This growth monopolizes the site and thereby reduces its productive capacity (fig. 6).

If, as often happens, fire breaks out in a young stand after cutting and before the slash has decayed, destruction of the young growth is nearly complete. Even a light fire in a young stand does far more damage than is outwardly apparent. Seemingly healthy trees in such stands frequently become infested with heart rot, although the fire scars may heal over. Trees damaged by fire when young can not be expected to maintain a vigorous growth. On the contrary, the rate of growth will gradually decrease as the decay established in the fire scar extends through the stem.

The early ascendancy of the useless species and the long time which must elapse before seedlings of the more valuable kinds can replace the inferior sprout growth, represent a distinct loss. If

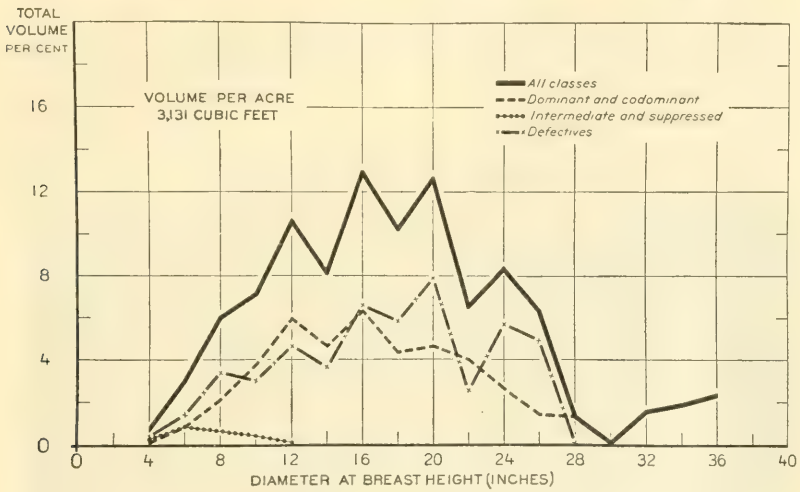

FIGURE 6.—VOLUME DISTRIBUTION IN LIGHTLY CULLED STANDS BY TREE CLASSES: OAK-CHESTNUT-HICKORY TYPE

A large proportion of the volume of lightly culled stands is in trees 16 inches and more in diameter.

fires again sweep through such stands, as too often happens, the productive capacity of the site may be totally destroyed.

EFFECT OF CHESTNUT BLIGHT

The nature, extent, and effects of the chestnut blight are not generally understood locally. Only during the last four to six years has any attention been paid to its progress. The damage done by the blight has generally been mistakenly attributed to insects. The blight has spread rapidly since 1927 and is affecting chestnut in farm woodland as well as in other timberland in all parts of both counties.

The blight is a fungous disease that attacks the living bark and outer sapwood, forming cankers which finally girdle and kill the part affected. Although the blight does not damage the wood, the dead part of the tree is quickly attacked by wood-destroying fungi and by insects and "timber worms," all of which combine to cause

rapid deterioration. The effects of these agencies have often been confused with the effects of the blight because their attacks occur so soon after the blight has killed the affected parts.

As the farmers of the section have depended mainly on mast crops to fatten their hogs, and as chestnuts have formed a large proportion of this crop, one effect of the blight will be to reduce this source of feed.

A more important effect of the blight is the killing of standing chestnut. Many farmers intend to hold their chestnut timber for better prices because lumber prices are now at a very low level. The heartwood of blight-killed chestnut is usually sound for about five years after death, and only the sapwood is immediately attacked by rot. Chestnut pole timber should be sold as soon as a market can be found, since users will not buy after sapwood has rotted.

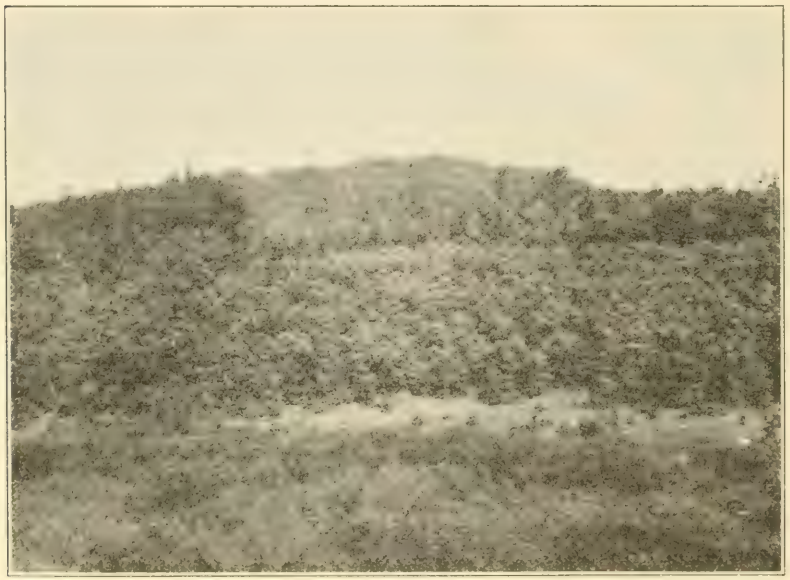

FIGURE 7.—Dense reproduction of oak which has occupied the recently abandoned crop and pasture fields throughout the gently rolling glade area of Nicholas and Webster Counties. Three stages of growth are represented here. Every effort should be made to protect such growth and to improve it by occasional thinnings

EFFECT OF ABANDONMENT OF MARGINAL FARM LANDS

Abandonment of lands formerly used for agriculture has generally been quickly followed by the establishment of forest growth. Such factors as the existence, position, and species of seed trees, the degree, evenness, and exposure of slopes, and the direction of the prevailing winds have determined the character of regeneration. For example, on the Dekalb silt loam and on the dry slopes and coves of Grassy Creek in Webster County the oaks predominate because the forests surrounding the abandoned fields are composed largely of oak trees. (Fig. 7.)

Besides those old-field stands consisting chiefly of white, red, and scarlet oaks, designated here as the oak type, there are others con-

sisting mainly of yellow poplar, designated as the yellow-poplar type. A third class of stands, in which oak and yellow poplar are associated with various inferior species, is designated as the miscellaneous-species type. Nearly pure stands of black locust have been observed, but because of its short life and its susceptibility to the locust borer, black locust is not treated here as a separate type. The more prevalent invading species increase in numbers and gradually dominate the site to form eventually one of the three types mentioned.

The types may best be described by examples of specific, representative stands. A 13-year-old stand of oak occupies a north slope in Webster County on a field which was abandoned 14 years ago. Except for a few sprouts, the present growth seeded in from the mature trees on the slope above the field.

Practically all the trees are under 4 inches in diameter and average 18 feet in height. There are 3,408 trees to the acre, uniformly distributed. White oak alone constitutes 86 per cent of the total and scarlet oak 6 per cent. Red maple, hickory, dogwood, sourwood, and chestnut make up the remainder.

Another old-field stand of practically the same age and height is fairly dense, having 2,380 trees per acre, all under 3 inches in diameter breast high. White oak composes 48 per cent, red oak 19 per cent, and red maple, chestnut, and hickory the remainder.

Table 21 shows the diameter-distribution and number of trees of three older stands, all situated on Dekalb stony silt loam. The first is on a slope, the second in a cove, and the third on a slope. All face south or west.

Stands of yellow poplar occur on slopes or in coves facing north or northeast. Most of these are on fields abandoned since the Civil War, and after lumbering began. Because the rich fertility of the cove heads and slopes was rapidly reduced by erosion, the period of cultivation was too short to eradicate entirely the aggressively sprouting species such as chestnut, black locust, sassafras, and sumac, but enough yellow-poplar seed blew in from the near-by trees to take eventual possession of the site.

TABLE 21.—*Number of trees, by diameter classes, on 1 acre in three representative old-field stands of oak*

Diameter class	25 years old		35 years old		45 years old	
	Number	Per cent	Number	Per cent	Number	Per cent
4 to 10 inches	406	97.0	206	93.7	178	77.9
12 to 22 inches	10	2.5	14	6.3	42	18.3
24 inches and up [1]	2	.5			9	3.8

[1] Trees already present when stand was established.

As in the case of the oak, there is much difference between stands even when they are of the same age. Yellow poplar forms 55 to 87 per cent of the total number of trees, other valuable species 5 to 43 per cent, and inferior species 2 to 8 per cent. Three stands of practically the same age (26 to 27 years) had from 234 to 438 trees per

acre. Figures 8 and 9 show the distribution of diameters and volume in one of these stands.

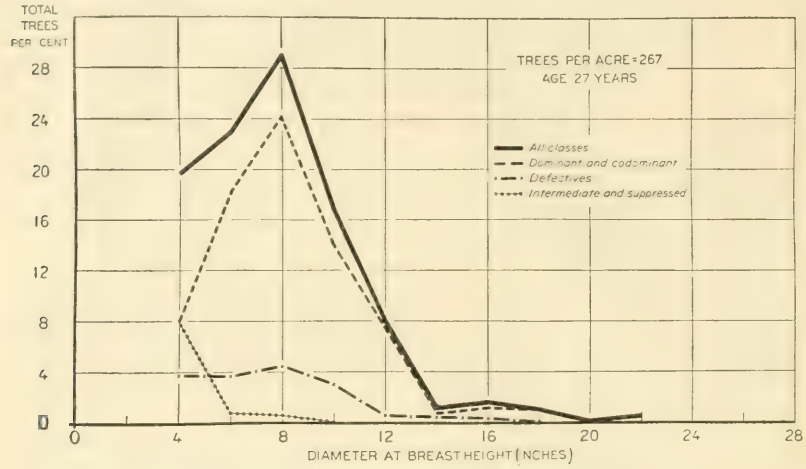

FIGURE 8.—STEM DISTRIBUTION IN OLD-FIELD STANDS, BY TREE CLASSES: YELLOW-POPLAR TYPE

The dominant and codominant trees make up a relatively high percentage of the old-field stands.

Stands of the miscellaneous-species type are also common in this section. Table 22 shows the mixed composition of three representa-

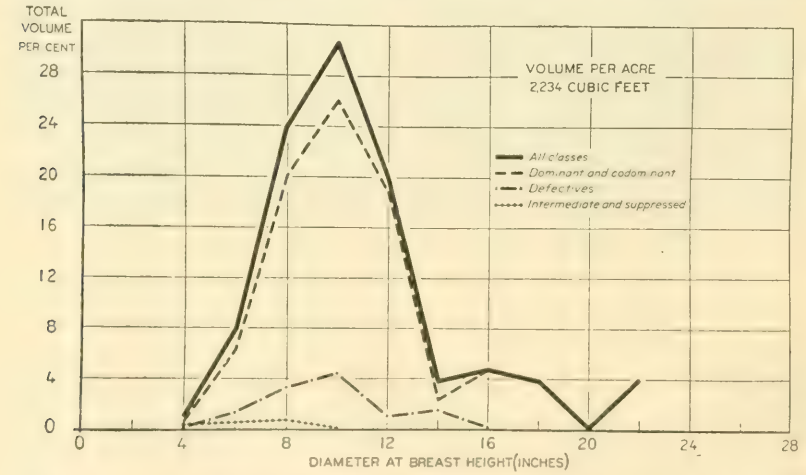

FIGURE 9.—VOLUME DISTRIBUTION IN OLD-FIELD STANDS, BY TREE CLASSES: YELLOW-POPLAR TYPE

Most of the volume of old-field stands is in the dominant and codominant trees.

tive stands of this type. These stands are on steep slopes too rough for farming.

TABLE 22.—*Composition of three representative old-field stands of the miscellaneous-species type*

Species	3-year stand	16-year stand	30-year stand	Species	3-year stand	16-year stand	30-year stand
	Per cent	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*
Yellow poplar	3.2	4.6	12.5	Black locust	11.3	-------	5.0
Red oak	1.8	21.1	1.5	Black gum	------	------	4.2
White oak	2.6	25.1	7.4	Sassafras	-----	36.6	36.6
Chestnut oak	4.2	------	.9	Sourwood	---	- -	2.1
Hickory	6.2	9.7	12.2	Dogwood	7.8	.	-------
Chestnut	12.4	1.1	4.5	Sumach	41.3		-------
Sugar maple	1.0	-------	3.0	Elderberry	4.6	...	-------
Red maple	.2	-------	8.9	Witch hazel	.2	..	------
Beech	.2	.6	-------				
Yellow birch	.2	-------	... ..	Total	100.0	100.0	100.0
Black cherry	.8	------	------				
Cucumber magnolia	.2	....	-------		*Number*	*Number*	*Number*
White ash	1.0	.....	-------				
Ohio buckeye	-------	1.2	-------				
Butternut	.8	-------	1.2	Trees per acre	1,988	1,750	336

DISTRIBUTION OF FOREST COVER BY SPECIES

SOIL TYPE AND DISTRIBUTION OF SPECIES

The great number of tree species found in this section is characteristic of the southern Appalachian hardwood forest. On all soil types except the Upshur stony silty clay loam, chestnut is the most abundant species, followed by white oak, yellow poplar, beech, the black oaks, and hickory. Although most of the species are found on nearly all soils, their relative abundance varies.

On Dekalb stony silt loam, the most numerous trees in order of their abundance are chestnut, white oak, yellow poplar, hickory, beech, black oak, and basswood. Yellow poplar, basswood, and butternut are relatively more abundant than on any other soil type.

On Dekalb silt loam the chestnut, white oak, beech, sourwood, black oak, red maple, and chestnut oak are most abundant. Sourwood, hemlock, and sassafras are relatively more abundant than on other soils.

On rough stony land, beech, birch, sugar maple, black gum, magnolia, dogwood, and white ash occur more abundantly than elsewhere. The most common trees on this soil type are chestnut, beech, white oak, black oak, hickory, yellow poplar, sugar maple, and black gum.

On Dekalb stony loam the most abundant trees are chestnut, black oak, chestnut oak, white oak, black locust, sourwood, and hickory. Chestnut, chestnut oak, black locust, and black cherry attain their greatest relative abundance on this type of soil. Chestnut forms over one-third of the total stand.

The limited area of Upshur stony silty clay loam supports various species with yellow poplar, beech, sycamore, and sugar maple predominating.

Dekalb loam, which is confined chiefly to ridge tops, is also relatively unimportant because of its restricted area and irregular occurrence. Chestnut and white oak, hickory, black oak, and red maple are the species found most often on this soil.

TOPOGRAPHY AND DISTRIBUTION OF SPECIES

Topography as a factor in the distribution of species is important chiefly on the slopes of the broader valleys where the contrast be-

tween slopes with different exposures is most pronounced. The growth in coves is also affected by the direction of exposure.

In ascending a cool, moist slope with a northern or an eastern exposure a mixture of many species is found, with yellow poplar predominating and often forming pure stands. As the ridge crest is approached, the mixture changes to one of chestnut oak, hickory, and black gum; below, on the opposite slope, with its southern or western exposure, the stand consists chiefly of oak.

Definite combinations of species are often associated with particular types of topography. Two of the combinations most generally observed are designated here as the oak-chestnut-hickory type and the oak-chestnut-poplar type. The first is more often associated with the dry upper slopes and narrow ridges; it is also the most common combination on the gently rolling topography of the glade area. The second generally occurs on the less-exposed middle and lower slopes.

The number of species is largest on the long, smooth, moist slopes and benches of the deeper valleys, on the lower slopes of the narrow, sheltered valleys, and at the heads of moist coves. For the sake of simplicity such combinations have been designated here as the miscellaneous-species type.

OWNERSHIP OF FOREST LANDS

Nearly half of the forest land is held by individuals in small scattered tracts, mainly in "surface" ownership.[11] The remainder, in large blocks, is held in surface or "fee" ownership by corporate interests. (Table 23.)

Large lumber companies own approximately 19 per cent of the timberland in Nicholas County and 44 per cent in Webster County. A large portion of these tracts contains only nonmerchantable timber. It is being held for various reasons which are discussed later.

Coal companies own in fee approximately 12 per cent of the land in Nicholas County but practically none in Webster. This is in addition to the tracts owned by operators of mineral and timber together, whose holdings have been included in the lands owned by lumber companies. As a matter of fact, some of the mine corporations are affiliated with, or subsidiary to lumber organizations, so that the consolidation of the timber and mineral resources is all the more complete.

TABLE 23.—*Ownership of forest land in Nicholas and Webster Counties, 1927*

Ownership	Nicholas County		Webster County	
	Acres	*Per cent*	*Acres*	*Per cent*
Farm woodland [a]	49,000	14.1	66,000	20.8
Individually owned				
Small scattered tracts [b]	116,500	33.6	90,000	28.4
Large tracts (500 acres or over)	13,800	4.0	18,000	5.7
Lumber and coal corporations	107,000	30.8	141,900	44.8
Land-holding organizations	60,700	17.5	1,000	0.3
Total forest land	347,000	100.0	316,900	100.0

[a] From U. S. Census of Agriculture, West Virginia, 1925 (9).

[b] Includes areas owned by large corporations.

[11] "Surface" ownership does not include any mineral rights. "Fee" is ownership of both surface and mineral rights.

RELATION OF OWNERSHIP TO METHODS OF UTILIZATION

Methods of forest utilization are but little influenced by the character of ownership. If timber is sold by a certain coal land corporation, for example, the only requirement is that the trees be cut to a diameter limit, generally above 14 inches. The purpose is to save the smaller trees for the use of those who will eventually mine the coal. If timber is sold by farmers or other small holders a minimum diameter limit may or may not be agreed upon. Trees of certain species may or may not be reserved, depending upon the inclination of the seller. Stipulations are seldom made as to how the tract shall be cut. In any event the farmer is in a position to give personal attention to the way in which his woodland is cut over should he wish to do so.

In the case of lumbermen cutting their own tracts, there is little evidence that they take any measures to perpetuate the forest other than by cutting to a diameter limit.

Small holdings, such as those included within farm boundaries, are usually close to roads and can be reached by portable mills. Tram roads are sometimes necessary, but in any case only a relatively small investment is required.

The larger tracts, on the other hand, can be made accessible only through heavy investments in logging equipment. The construction cost alone of a narrow gauge railroad amounts to about $3,500 a mile. For this reason operators consider that a million feet of timber must be available for each mile of railroad in order to keep unit costs within reasonable limits.

Large tracts lend themselves more readily than small tracts to management for sustained yield. At least one of the prerequisites of forest management—sufficient volume of timber to enable the production of steady supply in reasonably large quantities—is satisfied by large holdings; another advantage is that the overhead costs for protection and administration, being spread over a large acreage, are smaller per acre than in the case of small tracts.

PRESENT ORGANIZATION OF FOREST INDUSTRIES

Five kinds of wood-using industries are represented in the section: Sawmills, a pulp and paper mill, a dowel and handle factory, a woodenware plant, and a tannery.

PORTABLE SAWMILLS

Lumber is the principal product manufactured by the portable mills, but some of them also saw lath and have an annual output of 750 to 7,000 ties per mill. The annual output of a portable mill ranges from 500,000 to 4,500,000 feet of lumber. These mills depend almost entirely upon small tracts of farmer-owned timber. Because of their mobility they can reach small virgin tracts, as well as the more accessible cut-over areas. Logs are also purchased, and the smaller mills do custom work. Timber is purchased by the "boundary" or by the acre, rarely by the thousand board feet. Stumpage is purchased at an average of $5 a thousand for virgin timber, consisting mostly of oak, yellow poplar, and chestnut, and $3 for merchantable second growth. Because he is able to buy stumpage very cheaply, the mill operator can realize a profit despite his often wasteful and inefficient logging and milling methods.

The combined cost of felling and skidding is reported to average $6 per thousand feet. Logs bring about $8 to $9 per thousand feet log scale, delivered at the mill.[12]

Logs are transported by either standard or narrow gauge railways on some of the larger portable operations. Tram roads and inclines are also used. If the mill is situated on the timber tract the logs are skidded direct to it. Motor trucks are also used in logging by mills situated on Class A roads, and logs from farm tracts are frequently hauled over relatively long distances by wagon.

Hauling logs by rail costs from $4 to $10 per thousand board feet, depending on the width of gauge and the length of haul. The cost of hauling by horses averages $5 per thousand feet and by tram road $2 per thousand.

The average cost of sawing is about $6 per thousand board feet. Lumber grades usually run around 35 per cent No. 1 common and better, and 65 per cent No. 2 common and below.

The lumber is hauled by truck from 3 to 16 miles to points on the Baltimore & Ohio or the New York Central railroads. In most cases it is marketed through wholesalers who pay $40 to $45 per thousand board feet for the best grade of white oak and yellow poplar and $30 to $35 for average mill run at the railroad. The average cost of hauling is about $8 per thousand feet.

The ties go to the Baltimore & Ohio, the New York Central, and the local narrow-gage railroads. These railroads purchased about 4,000,000 feet of ties and 300,000 feet of lumber in 1927. Standard ties bring an average of $1 per tie, or $26 to $28 per thousand feet.

BAND-SAW MILLS

The timber supply of the large mills comes from several sources. Some of it is from their own land. Timber rights are also purchased from corporations or individuals, including farmers.

Stumpage values differ according to accessibility, logging costs, and quality of timber. Average prices for both virgin and second growth run from $3 to $6 per thousand board feet. The combined cost of felling and skidding is reported to average $8 per thousand. Logs are brought to the mill by standard or narrow-gage railroad at a cost ranging from $4 to $10 per thousand feet.

Logs are also purchased by some of the mills at from $9 to $25 per thousand, delivered at the mill. From 200,000 to 1,000,000 feet a year are purchased.

The annual lumber output of a band mill runs from 4,500,000 to 30,000,000 feet. The total output of all band mills in the two counties, including ties and lath, is about 107,000,000 feet annually. This will be increased by about 35,000,000 feet upon the completion of two other mills. The section produces yearly about 35,000 cords of spruce and hemlock pulpwood, 10,000 cords of hemlock bark, and 25,000 cords of slab wood. Spruce pulpwood, delivered, sells for about $18 a cord, hemlock for $12.

Milling costs average about $7 per thousand feet.

The grades of lumber obtained from old-growth timber range from 27 to 40 per cent No. 1 common and better. Not enough merchantable second growth has been cut to determine the average

[12] In this discussion, costs given for various operations, and prices paid for stumpage or received for timber are for the year 1927–28, when the field work for this study was carried on.

percentage of grades. One band mill, which is utilizing the timber from tracts containing much young growth, reports 40 per cent No. 1 common and better.

The average price f. o. b. mill is about $35 per thousand feet with higher prices for poplar and oak.

All the lumber manufactured is shipped out of the State to northeastern, central, and midwestern markets. The output is disposed of either through wholesalers or through the manufacturers' own selling organizations.

Two of the large mills sell hardwood and softwood slabs, tanbark, pulpwood, and hardwood logs, the output going to the local wood-using plants.

OTHER MILLS

The pulp and paper mill is a sulphite mill with a daily output of 100 tons of wood pulp. It uses annually 35,000 cords of spruce and hemlock logs and 17,000 cords of soft-wood slabs, obtained entirely from the old-growth stands.

The clothespin and wooden-dish factory uses native beech and maple logs which cost, delivered at the yard, $22 per thousand feet for beech, and $28 and $35 for the two grades of maple used.

The dowel and handle factory uses native beech only, paying $21 and $25 per thousand feet, delivered, for the two grades of logs that are purchased.

The tannery buys 10,000 cords a year of native hemlock bark. Chestnut-extract liquor is also shipped in from Tennessee.

FOREST INDUSTRIES AND LOCAL LABOR

The forest industries are the main source of employment for local labor. Most of the work in the woods and all the sawmill work are performed by native labor. The tannery and the pulp and paper mill employ some foreign labor.

The average wage paid woods labor is about $3.50 a day and board. Teams bring an average of $2.50 and feed.

The money wages of mill workers are slightly higher, but the real wages received may be less because the woods workers usually receive their board. Wages in the secondary industries differ according to the degree of skill required. Skilled labor commands from $5 to $8.50 a day. The lowest daily wage paid to unskilled male labor is $3.50. The clothespin factory and the paper mill employ women at piece work for about $2.50 a day. These two plants furnish the only important outlets for women's labor within the territory.

During the "off" season farmers work in the woods and to a smaller extent around the portable mills, sometimes using their farm teams which otherwise would remain idle during the winter. Money earned in this way often forms the greater part of their total cash income.

CHANGES IN EXTENT AND CHARACTER OF FOREST RESOURCES

An increase in abandonment of marginal farm lands is bound to occur as the result of removing the old-growth timber. Most of this land will revert to forest. The area in forests at the end of the next 20 years may be about 692,000 acres, or 28,000 acres more than at

present. Some new lands or old fields may be cleared, but it is unlikely that such acreages will permanently be used for agriculture.

On the forested areas the character of the growth is undergoing a rapid transition. The area of merchantable timber, now some 283,000 acres, probably will shrink to 183,000 acres, or only 26 per cent of the total forest area, within the next 20 years. The remainder will consist almost entirely of nonmerchantable growth.

Without adequate fire protection much of the remainder will be more or less badly burned, and consequently of greatly decreased capacity for further growth and value. Even if adequately protected, its maximum value can not possibly be realized unless it is also placed under management.

TREND IN OWNERSHIP

Land ownership within the section, because of the potential value of the mineral resources, is marked by high stability and little tax delinquency. The present policy of most of the large landowners is to retain possession of cut-over areas with a view to obtaining mine timber whenever the exploitation of coal becomes commercially feasible. One of the largest operators, who owns thousands of acres of cut-over land, is holding it for future growth, perhaps intending to harvest hardwood pulp after the present supply of native softwoods is exhausted.

Although the tendency is toward greater concentration of ownership, the policies of the various classes of large land holders are by no means definitely established. There is no certainty that all of the land is underlaid with coal, nor can anyone predict when even the best of the coal will be exploited on a large scale, considering the present state of the industry.

So far as the surface of the cut-over land is concerned, no definite attitude toward its future use or disposal has been taken. Rather, the policy is one of continuing possession and watchful waiting. Some owners hope that the Federal Government may take the problem of the least productive lands off their hands by acquiring it for national forests.

In the meantime the numerous small stands of good timber are being rapidly exploited. Only the isolated, relatively inaccessible tracts will be left when the period of large-scale lumber production comes to an end.

POSSIBILITIES OF FOREST LANDS UNDER MANAGEMENT

From the standpoint of private owners, the desirability of holding forest land for future timber production depends primarily upon the prospect that the income from the forest in the long run will repay the costs, together with a reasonable profit. The net returns possible from growing timber are largely dependent upon the nature and efficiency of the methods employed in handling the existing stands. Mere protection of forests from fire will not insure the growth or improve the position of the most valuable species. It is necessary that the existing forests be utilized in such manner as to leave the remaining stand in the best possible condition for future productivity. In any event, sufficient trees of the better species should be left over a long enough period to produce saw timber and furnish seed for future growth. The amount of net return will depend in the first place upon the rate of tree growth under various conditions.

RATES OF GROWTH OF INDIVIDUAL SPECIES

The rates of growth of individual species can be treated here only in a summary way. Relationships between tree growth and topography and soil are very complex. There is little doubt that certain soils, such as Dekalb silt loam and Upshur stony silty clay loam, are more favorable to rapid growth than are Dekalb stony loam, Dekalb stony silt loam, or rough stony land. The better soils occupy in general the more gentle slopes and the broader ridges; the poorer soils occupy the narrower ridges and the rugged slopes.

Tables 24 and 25 give generalized growth rates for dominant and codominant trees of various species in uneven-aged stands and in even-aged old-field stands, respectively.

TABLE 24.—*Rate of diameter growth of dominant and codominant trees in uneven-aged stands* [1]

Present diameter	Amount by which diameter will increase in 20 years		
	Chestnut oak, white oak, hickory, black gum	Beech, maple, birch, hemlock, white ash, black oaks	Yellow poplar, basswood, cucumber, walnut, butternut, black cherry, black locust
	Inches	*Inches*	*Inches*
0 to 3 inches	1.5–3.0	3.0–4.0	4.5–6.5
4 to 7 inches	2.5–3.5	3.0–4.0	4.5–7.0
8 to 11 inches	2.5–3.5	3.5–5.0	4.5–6.5
12 to 15 inches	2.5–3.5	3.0–5.0	3.5–5.0
16 inches and over	3.0	3.0–4.5	3.0–4.5

[1] Based on measurement of 1,178 trees in Nicholas and Webster Counties.

TABLE 25.—*Rate of diameter growth of dominant and codominant trees in even-aged stands* [1]

Present diameter	Amount by which diameter will increase in 20 years		
	Hickory, white oak	Red oak, black walnut, butternut	Yellow poplar
	Inches	*Inches*	*Inches*
0 to 3 inches	3.0–4.0	4.0–5.0	4.0–6.5
4 to 7 inches	3.5–5.0	5.0–6.5	7.5–9.0
8 to 11 inches	3.5–5.0	5.0–7.0	[2]
12 to 15 inches	[2]	6.0–7.0	[2]

[1] Based on measurement of 194 trees in Nicholas and Webster Counties.
[2] No data.

Intermediate and suppressed trees in crowded stands grow much more slowly than the dominant individuals, yet many of these, if in healthy condition, can be counted on to increase their rate of growth when they are released from suppression by the cutting of their larger neighbors. In many stands the growth rate of various species freed from suppression has increased by as much as 200 to 300 per cent. Species ordinarily considered slow growing, such as white oak,

chestnut oak, hickory, and hemlock, show a striking capacity for recovery after their release and have increased their growth rate sometimes by as much as several hundred per cent.

GROWTH OF MIXED, UNEVEN-AGED STANDS

The rate of growth of uneven-aged stands was computed by applying the rates of diameter, height, and volume increment for various-sized trees of individual species to tables representing the average composition of the stand. For each type of forest, these stand tables were prepared by tallying the trees on several sample tracts so as to show the number in each species and diameter class on an average acre. For purposes of predicting increment following cutting, it was assumed that the growth of intermediate, suppressed, and badly defective trees can be ignored. No growth was calculated for chestnut, even for dominant trees, because of the probability that most of the chestnut will succumb to the blight within a very few years. For this reason, the growth during the last 20 years as shown in Table 26 is less than the actual growth. It probably also gives a very conservative indication of the growth that may be expected on the same stands during the next 20 years. The volume growth is expressed in both board feet and cubic feet. Board-foot volume applies only to trees 10 inches or over in diameter breast high; cubic volume applies to all trees 4 inches and over.[13]

TABLE 26.—*Volume growth following cutting in uneven-aged mixed stands*

Method of cutting and type of forest	Present dominants and codominants								All other classes [a]	
	Volume per acre 20 years ago		Present volume per acre		Total growth in 20 years		Average annual growth		Present volume per acre	
	Bd. ft.	*Cu. ft.*	*Bd. ft.*	*Cu. ft.*	*Bd. ft.*	*Cu. ft.*	*Bd. ft.*	*Cu. ft.*	*Bd. ft.*	*Cu. ft.*
Lightly culled:										
Oak-chestnut-hickory	1,886	646	4,630	1,324	2,744	678	137	34	5,605	1,817
Oak-chestnut-poplar	4,563	1,044	7,930	1,738	3,367	694	168	35	6,179	1,719
Miscellaneous species	4,787	1,181	7,679	1,829	2,892	648	145	32	4,427	1,408
Cut to diameter limit:										
Oak-chestnut-hickory	424	261	1,894	803	1,470	542	74	27	3,249	1,251
Oak-chestnut-poplar	789	281	2,013	682	1,224	401	61	20	3,110	1,633
Miscellaneous species	1,283	453	3,224	1,017	1,941	564	97	28	2,731	1,013
Heavily cut over:										
Oak-chestnut-hickory	31	129	564	454	533	325	27	16	1,870	949
Oak-chestnut-poplar	0	17	270	268	270	251	14	12	2,100	639
Miscellaneous species	535	190	1,704	523	1,169	333	58	17	2,473	837

[a] Volumes in "all other" column are relatively large, because they include chestnut and other defectives which are really of dominant and codominant crown class.

Table 26 indicates only roughly what may be expected in unmanaged and unprotected stands following cutting by the usual methods. The application of these data to any given tract of forest must take into account the conditions peculiar to that tract. For example, fire influences the rate of growth in practically all stands. Two timber tracts alike in every other respect may grow at widely different rates on this account. Irregular cutting methods, too, influence subsequent growth. Much more damage has been done to

[13] All computations throughout this report that involve board-foot volume are based on the Scribner Decimal C rule, since the only available volume tables are in terms of this rule. The rule in general use in the section, however, is the Doyle-Scribner rule. This has also been officially adopted by the National Hardwood Manufacturers' Association. It gives values roughly 30 to 50 per cent lower than does the Scribner Decimal C rule, depending on whether the stand contains a fair proportion of large-sized trees or whether the larger trees have been removed.

small trees on some operations than on others, depending upon the logging conditions and the current attitude of timberland owners and operators toward forestry.

GROWTH OF EVEN-AGED OLD-FIELD STANDS

The rate of growth in several representative old-field stands is shown in Table 27. There is considerable variation in the volume that is produced in different stands, because of differences in productive capacity of the site, in the proportion of species associated in mixed stands, and in the density of stocking. It is not possible to say how much increase would result from thinnings or improvement cuttings, but there is no doubt that the increase would be significant. Investigations in thinned and unthinned oak stands in the central hardwood section in New York have established the fact that through systematic thinnings in even-aged stands the period required for oaks to attain diameters of 12 inches or over may be reduced by 30 to 50 years (*7*).

TABLE 27.—*Volume and rate of growth of selected even-aged old-field stands*

Age of stand (years)	Number of trees per acre	Present volume				Mean annual growth for all trees	Average annual growth of dominant and codominants during last 20 years
		All trees		Dominant and codominants			
		Cu. ft.	*Bd. ft.*	*Cu. ft.*	*Bd. ft.*	*Cu. ft.*	*Cu. ft.*
OAK TYPE							
25	418	843	510	598	300	34	29
35	220	1,440	3,062	948	2,112	41	47
45	229	2,057	5,885	713	2,768	46	36
YELLOW-POPLAR TYPE							
25	438	902	282	741	282	36	36
26	234	746	452	654	452	21	32
27	267	2,234	5,928	1,941	5,346	83	91
MISCELLANEOUS-SPECIES TYPE							
30	236	1,534	2,463			51	39

YIELDS OF SAW TIMBER

The number of years required to produce saw timber in each of the various types of forest will depend on the past treatment and the manner in which these forests are handled in the future.

Roughly speaking, a cut-over tract should contain from 2,500 to 4,000 board feet per acre in trees at least 14 inches in diameter breast high before it can again be profitably logged for saw timber. For the farmer who does his own cutting and hauls his logs to a mill it will suffice if only a few trees per acre reach a diameter of 14 inches. But it would hardly pay to set up a portable mill on tracts with less than 2,500 feet of saw timber; and on tracts of large size, selective railroad logging would not be feasible until at least 4,000 feet an acre could be obtained.

To predict accurately the yields to be expected from the cut-over, mixed, and uneven-aged stands of the section is practically out of the question. Nevertheless, no extensive calculations are needed in order to say that the more heavily cut stands, from which all or most of the merchantable timber has been logged, and on which much of the thrifty young growth has been injured or destroyed, will require a discouragingly long time to again furnish a profitable crop.

By applying the growth data obtained from sound, growing trees on various sites to specific stands recently cut over, the possible yields of existing stands within the next 20 to 40 years may be roughly estimated.

Table 28 gives an example of what might be expected from stands cut so heavily as to remove all merchantable trees over 12 inches in diameter, and Table 29 shows the possible yields from two stands in which some of the larger trees were left.

TABLE 28.—*Approximate yields of saw-timber attainable in two selected, heavily cut stands*

STAND A

Species	Healthy growing trees left after last cut		Diameters and volumes after—			
			20 years		30 years	
	Trees per acre	Diameter breast high	Diameter breast high	Merchantable volume [1]	Diameter breast high	Merchantable volume [1]
	Number	*Inches*	*Inches*	*Board feet*	*Inches*	*Board feet*
Hickory	1	6	9		11	
Hickory	1	10	13		15	150
Cucumber magnolia	1	6	10		12	
Cucumber magnolia	1	10	14	100	16	150
Red oak	1	4	8		10	
Red oak	1	12	18	300	20	425
Birch	1	4	8		10	
Birch	1	10	14	100	16	150
Black gum	1	12	14	100	15	125
Black locust	1	4	9		11	
Black locust	1	10	12		13	
Chestnut oak	1	10	13		15	125
Red maple	1	4	8		10	
Basswood	1	8	14	150	16	200
Basswood	1	10	16	200	18	275
White ash	1	4	8		10	
Total	16			950		1,600

STAND B

Red oak	2	6	10		13	
Basswood	2	10	16	400	18	550
Beech	6	4	8		10	
Beech	8	6	10		12	
Beech	4	12	16	600	18	900
Sugar maple	2	4	8		10	
Total	24			1,000		1,450

[1] Trees less than 14 inches diameter breast high not included.

Table 30 indicates that it will take about 30 years for lightly cut stands again to produce saw logs in quantity and that approximately 3,000 to 5,000 board feet per acre will be available for selective cutting at the end of that period. Heavy cutting will yield a slightly higher immediate return but it may necessitate twice as long a wait before sufficient timber for the next cut will be produced.

The advantage of even crude diameter-limit cutting is evident in the shorter time that must elapse before the next crop can be harvested.

Also it causes the stand to be left in much better condition. Stands that have been cut during the last 25 years to some diameter limit, usually 12 to 14 inches, and that have not been damaged too severely by fire, now average from 5,000 to 6,000 feet per acre in trees 10 inches and up and are growing at the rate of 60 to 100 board feet per acre per annum.

TABLE 29.—*Approximate yields of saw-timber attainable in two selected lightly cut stands*

STAND C

Species	Healthy growing trees left after last cut			Diameter and volumes after—			
				20 years		30 years	
	Trees per acre	Diameter breast high	Merchantable volume [1]	Diameter breast high	Merchantable volume [1]	Diameter breast high	Merchantable volume [1]
	Number	*Inches*	*Board feet*	*Inches*	*Board feet*	*Inches*	*Board feet*
Sugar maple	4	4		8		10	
Yellow poplar	4	5		11		13	
Do	4	7		13		15	700
Hemlock	4	9		12		14	250
Beech	4	4		8		10	
Do	8	8		12		14	800
Yellow birch	4	14	440	18	900	19	1,050
Black cherry	8	4		10		13	
Do	8	5		12		15	1,350
Do	4	7		13		16	850
Do	4	9		15	700	18	1,250
Total	56		440		1,600		6,250

STAND D

Cucumber	2	10		14	170	16	275
Sugar maple	2	4		8		10	
Do	2	12		16	390	18	500
Do	2	16	390	20	680	22	850
Beech	6	6		10		12	
Do	2	8		12		14	200
Do	4	10		14	400	16	625
Hickory	2	8		11		13	
Do	2	10		13		15	300
Yellow birch	2	4		8		10	
Do	2	6		10		12	
Basswood	2	14	280	19	635	21	825
Red oak	2	4		8		10	
Total	32		670		2,275		3,575

[1] Trees less than 14 inches diameter breast high not included.

The annual net incomes possible from a given tract cut to various diameter limits are illustrated by the following hypothetical example:

Given a tract of 6,000 acres, 3,000 feet per acre being available for cutting to a 14-inch limit or 4,000 if cut to a 10-inch limit, exclusive of additional volumes resulting from growth during the cutting period:

With light cutting, a 30-year cutting cycle may be used, a different 200-acre tract being cut each year for 30 years. At the end of this period the 30 years of growth on the 200 acres first cut over will have produced a stand of approximately 5,000 board feet per acre, and the program of annual 200-acre cuttings may be repeated.

With heavy cutting, a 60-year cutting cycle will be required for a continuous operation, 100 acres being cut annually. At the end of the 60 years 7,000 feet per acre would be available for clear cutting on the first 100 acres, or 5,000 per acre for selective cutting.

Assuming that annual taxes would amount to 15 cents an acre and that fire protection would cost 2 cents an acre in each case, the annual net income derived from each method would be as shown in Table 30.[14]

TABLE 30.—*Hypothetical yields of a 6,000-acre tract under light cutting during a 30-year cycle and under heavy cutting during a 60-year cycle*

Item	Light (selective) cutting	Heavy (clear) cutting
Volume per acre at beginning [1] ..... board feet	3,000	4,000
Average total increment per acre during 1 cutting cycle [2] ..... do	375	2,250
Average volume cut per acre ..... do	3,375	6,250
Area cut each year ..... acres	200	100
Average volume cut annually ..... board feet	675,000	625,000
Stumpage value per 1,000 feet [3] ..... dollars	6.50	6.00
Total stumpage value of annual cut ..... do	4,387.50	3,750.00
Less annual taxes and fire protection on 6,000 acres ..... do	1,020.00	1,020.00
Net annual income ..... do	3,367.50	2,730.00
Net income per acre ..... do	.56	.46
Net annual income per acre, second cycle ..... do	.91	[4]

[1] Volume of trees 14 inches and over and 10 inches and over, respectively.
[2] Average increment for 0 to 30 years on trees 14 inches and over at time of cutting, for light cutting; and increment for 0 to 60 years on trees 10 inches and over at time of cutting, for heavy cutting.
[3] The difference between the stumpage values of trees 14 inches and up and trees 10 inches and up is due to the greater costs of logging and milling the smaller-sized trees, and to the lower grades of lumber sawed from the smaller logs.
[4] Income not calculated for second 60-year cycle.

After 30 years the annual net income from the tract cut to a 14-inch diameter limit would increase by reason of the increase in growth brought about by judicious cutting.

The available volume per acre might then average 5,000 feet, permitting an annual cut of 1,000,000 feet from 200 acres. With stumpage values and costs remaining the same, the net income per acre during the second 30-year period would be $0.91, the capitalized value of which at the beginning of the period (30 years hence) would be $12.57.

The present capitalized value of the annual net income per acre ($0.56) received during the first 30 years plus that received during the second 30-year period ($0.91) amounts to $11.23. This is $3.88 more than the corresponding figure for the same period for the stand cut to a 10-inch limit.

Comparison of the returns per acre from selective and heavy logging indicates that if the land is to be held for timber growing the lighter cutting will yield the higher income. Should the owner decide to sell the 6,000-acre tract immediately rather than to hold it, he would receive, on the basis of current market values, about $9 an acre. This is $2.23 below the present capitalized value of the annual net income computed for selective cutting over a 60-year period.

YIELD OF PULPWOOD

Instead of saw timber, or in addition to it, forests in this section may be managed for the production of wood in other forms. Even though there is now little or no market for other products, it is probable that a demand for them can be developed. The increasing demand for hardwood pulpwood, for instance, undoubtedly will

[14] Interest on initial investment is not included because only forest properties already in operation are considered. The purpose is merely to compare future incomes possible from such properties through the different cutting methods described.

result in an extension of that market into this territory. One advantageous feature of growing pulpwood is the short interval required between crops. (See Table 31.)

Table 30 shows the entire usable volume in the average stand. However, the net income would be greater if the larger trees were cut for lumber than if they were cut for pulpwood. Hence in actual practice only part of the total yields indicated would be available for pulpwood. Furthermore, stands predominantly oak, or containing much oak and similar dense hardwoods, would furnish little pulpwood under the present standard pulping processes. (The semichemical pulping process, which is readily adapted to the conversion of hardwoods, may make the utilization of such species for pulp commercially feasible in the future.) Therefore, in case it was decided to grow pulpwood instead of saw timber on the 6,000-acre tract used in the illustration above, only a small yield could be expected during the first cutting period. Immediately following the cut for saw timber 2½ to 5 cords of pulpwood per acre would be available, according to whether the cutting had been heavy or selective. During this period the greater part of the income would still come from saw logs.

Assuming that the saw timber were to be cut selectively and that pulpwood logging would proceed simultaneously, the tract after 30 years would have been completely logged over for both products. Not all the trees 6 to 14 inches in diameter at the time of cutting would have been cut for pulp during this time, however. Species unsuited to this product, like oak, hickory, and ash, would be left.

TABLE 31.—*Average time required to grow hardwoods of pulpwood size and probable yields under present conditions*

Class of forest	Time required to grow trees to 6 inches diameter breast high	Approximate yield per acre
	Years	*Cords*
Old fields:		
Yellow-poplar type	20	18
Miscellaneous-species type	30	15
Heavily cut over	20	6
Cut to diameter limit	20	15

During the second cutting period the yield of pulpwood might be as much as 8 to 10 cords per acre, and there might be, in addition, 1,500 to 3,000 feet of high-grade saw logs, depending upon the proportion of the denser hardwoods.

Even though the existing hardwood forests can not be managed solely or even chiefly for the production of pulpwood, it seems likely that this may constitute an important by-product from many stands.

COMBINATION OF VARIOUS PRODUCTS

The best utilization of the mixed, uneven-aged hardwood forest would result if it were managed so as to yield a variety of products. In this forest, valuable species of all sizes are intermingled with those of little value. Such a condition favors the harvesting of several kinds of crop.

There is likely to be a demand in the future for saw logs, veneer logs, crossties, telephone poles, pulpwood, mine timbers, fence posts, and

perhaps extract wood. A tract capable of yielding several different products will be likely to produce a steadier and larger income than a tract yielding a single product. The values and sizes of various products obtainable from the average mixed hardwood forest in this section are shown in Table 32.

From 25 to 30 crossties constitute a thousand board feet. The practice of the mills cutting them is to use the heartwood of the timber for ties and the sapwood for lumber.

Fence posts from large white oak trees are better than those from small trees, which have too much sapwood to make durable posts. Posts average 50 to the cord. The few fence posts and rails made at present are used locally; rail fences are giving way to wire fencing. Chestnut and black locust furnish practically the entire domestic need at present.

TABLE 32.—*Specifications and values for products from mixed uneven-aged forests*

Product	Size of product		Approximate value [1]—			Species	Desirable minimum diameter breast high for cutting
	Minimum diameter at small end	Minimum length	Per thousand board feet	Per piece	Per cord		
	Inches	*Feet*	*Dollars*	*Dollars*	*Dollars*		*Inches*
Saw logs	10	10	8–9			All commercial	14
			50–65			White oak	
			45–60			Red oak	
Veneer logs	18	4	50–400			Walnut	20
			30–35			Yellow poplar	
			20–25			Red gum	
Crossties	7 by 9	8½	28–33	0.75		Oak, chestnut, black gum, others.[2]	14
				0.15–.25		White oak	14
Fence posts	4	6½		.15–.25		Chestnut oak	10
				.15–.25		Chestnut	6
				.40–.50		Black locust	6
Mine props	5	5		.10–.15		Oak, chestnut, maple, others.[3]	6
Mine collars	4	10		.40–.60		Same as above	6
Telephone poles	8	20		1.00–10.00		Chestnut	10
Pulpwood	4	4			8.00–9.00	All hardwoods except oak, hickory, and ash.	6
Fuel wood	2	1			1.00	Beech, black gum, birch, maple, oak, chestnut.[4]	
Extract wood	2	1			2.50	Chestnut [4]	

[1] Values are for products delivered on cars or at mill.
[2] Average tie.
[3] Other hard-textured woods such as beech, birch, black gum, black cherry, hemlock.
[4] Tops, branches, dead and defective trees.

Mine timbers must be of hard-textured woods. Props average 45 to the cord; collars, 35 to the cord. The possibility of return from the local sale of mine timbers is slight so far as the small land owner is concerned. The large companies who own mineral rights own most of the surface as well, and could supply their needs from their own holdings.

The values given for chestnut poles and extract wood are estimates. Untreated poles bring from $2.25 to $19.50 each, depending on the length. Chestnut trees of good form are cut for poles in some localities. The cutting is being accelerated because of the chestnut blight and because the preparation of poles requires but little capital or equipment.

The values shown for hardwood pulpwood and fuel wood are based on existing market prices in southern Kentucky, as there is no present market for these products in the section being studied. Very little wood is used for fuel, as coal is plentiful and cheap and underlies most of the farms so that it is directly available for domestic consumption.

Not all these products may be marketable at any one time from a given tract. While nature, with man's assistance, is constantly at work producing the raw material, the question of just what product or products should be manufactured can be answered only by a study of current market conditions. Fortunately the forest crop is unlike agricultural crops in that usually it need not be entirely removed at one cutting nor at any particular time to save it from deterioration. If prices are unsatisfactory or if the trees are too small for the manufacture of those products yielding the highest net returns, the harvest may be deferred until conditions are more favorable provided the owner can wait for income.

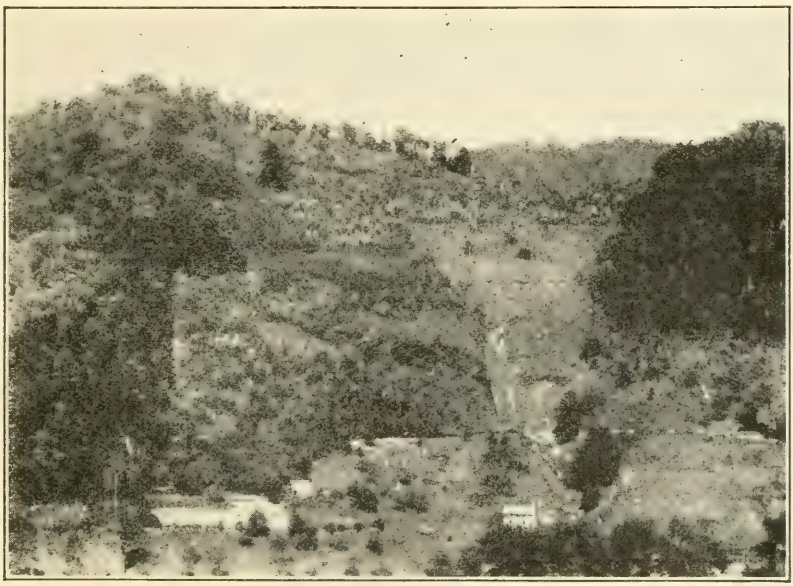

FIGURE 10.—Yellow poplar seeded in on this cool slope from the mature trees above. Such steep slopes should never be cleared

MANAGEMENT OF FARM WOODLAND

Much of the foregoing discussion applies equally well to large tracts and to small ones such as farm woodlands.

Although the market situation is now uncertain and far from satisfactory, partly because of overproduction, all the large tracts will be cut over within the next 15 to 20 years. Small holdings containing timber of good quality will then be in demand at good prices. Their present relative inaccessibility to market will be remedied by the construction of Class A roads which are now being built through this section.

Yellow poplar logs (fig. 10) for lumber, veneer, and pulpwood; black walnut for veneer; oak for ties, veneer backing, and lumber; and hickory for vehicle stock and handles will be readily salable at

good prices. The fact that some species will attain pole and tie size at the time that the others attain lumber and veneer-log size, especially where oak and yellow poplar are mixed, will make for more complete and profitable disposal of the products.

The possibilities of saw-timber production on old fields are indicated by Table 33.

TABLE 33.—*Average price per thousand feet for logs delivered at the mill*[1] *and number of years required for trees to grow to 14 inches diameter breast high on old fields*

Species	Period	Price	Species	Period	Price
	Years	*Dollars*		*Years*	*Dollars*
Yellow poplar	45	23.87	Red oak	55	20.33
Black walnut	55	119.92	Hickory	80	39.68
White oak	70	20.33	Sycamore	45	20.57

[1] Average log prices for 1924, Appalachian region. From Statistical Bulletin 21 (7).

What may be expected from careful management of existing mixed stands is indicated by the following example of results actually obtained on a farm wood lot in Webster County.

On a 40-acre tract of the oak-chestnut-hickory type three cuttings have been made. Thirty years ago 2,000 to 4,000 feet per acre of selected oak and poplar were removed from the virgin stand. Eleven years ago a second cutting took out 4,858 feet per acre, of which 3,233 feet was in the form of ties and 1,625 feet of saw logs. Two years ago a third cutting removed 2,077 feet per acre, 1,133 feet as ties, and the rest as saw timber. The present stand contains 228 trees per acre, 30 per cent of which are 10 inches and over in diameter, with a volume of 5,000 board feet per acre. The smaller trees from 4 to 10 inches in diameter have a volume of 245 cubic feet per acre.

The smaller healthy trees are mostly dominants, since the large timber has all been removed. There is, therefore, ample opportunity for rapid growth on the part of the vigorous young stock which has been left uninjured by the later cuttings.

The trees that are now 10 inches and over will be large enough for ties and lumber within the next 20 years, and there are enough smaller trees to warrant thinning should a demand arise for such products as mine props, pulpwood, or fence posts.

The stands that have grown up on old fields are especially valuable to their owners. Because of conditions favorable to rapid growth, such stands may contain from 5,000 to 14,000 feet per acre at 30 to 50 years of age.

Trees usually reach post size, tie size, pole size, and lumber size more quickly on old fields than on any other type of land. Growth in height and diameter is more uniform, and there is the additional advantage of freedom from suppression by large trees. The evenness of the stand, the comparatively small number of species, and the natural dominance of the more valuable trees are other favorable factors.

Present values of 14-inch logs may be somewhat below the averages as shown in Table 33, particularly in the case of black walnut.

These figures indicate that it may well be worth while for farmers to encourage the natural growth of well-formed trees of these more valuable species on worn-out fields and pastures, and even to restock

such lands by planting where it can be done at little expense. The uncertainty of natural, haphazard restocking on many old fields could be avoided by planting, since composition and density would be entirely under control. Either pure stands of yellow poplar or mixed stands containing poplar could be planted, depending on the site and on the products desired. One-year-old seedlings can be planted, spaced 8 by 9 feet, at a cost of $5 or $6 an acre.

Yellow poplar, black walnut, black locust, and black cherry would make a good combination. Black locust grows well during the first 20 to 25 years of its life. It should then be cut for posts, props, etc., along with the yellow poplar for pulpwood, leaving the black walnut, black cherry, and some of the best poplar for saw timber and veneer logs. The cost of planting and management could be met in part from this intermediate cutting and thinning.

The revenue possible from thinning is indicated by a stand of almost pure yellow poplar, near Cranberry, N. C., which was partly thinned when about 35 years old and yielded 8 or 9 cords of pulpwood per acre, worth $4 per cord.[15]

In most instances the sale value of the farm would be materially increased by the presence of a well-established stand of thrifty young growth.

COSTS OF HOLDING TIMBERLAND

The costs of holding land for timber growing consist mainly of taxes and the expense of fire protection. The cost of administrative and silvicultural measures would vary according to the intensity of forestry practice. Such costs would usually be more than offset by the increased yields and better quality of timber grown.

COST OF PROTECTION AGAINST FIRE

Expenditures for fire protection in this section are borne by the State and by private associations. The State spends 1 cent per acre per year, and the members of the Central West Virginia Fire Protective Association contribute an additional 1 cent per acre for such tracts as are owned by them. The extra sum spent on association lands has been well justified by the better protection afforded. At least 2½ cents and possibly 3 cents an acre must be spent, however, to ensure really adequate protection. This would provide for the maintenance of a permanent organization sufficient to cope with all fires in an efficient manner.

TAXATION OF TIMBERLAND

Timberland, like all other classes of property, is assessed under the so-called general property tax. The problem of determining the bases for the values placed upon different classes of timber is complicated by the presence of underlying mineral resources which may or may not be under the same ownership as the timber. This is true also of those smaller tracts which, together with improved land, constitute farm units. The land books fail to differentiate between forested and other areas, where the ownership is in fee or surface; nor is there any indication of the proportionate value given to forest land. In fact, although the various types of timberland have fairly specific

[15] United States Department of Agriculture, Forest Service, Branch of Research. monthly report, September, 1928, p. 11. [Mimeographed.]

values, these do not appear to be taken into consideration. For example, timberland held in fee may have been assessed at a valuation of, say, $25 an acre. Later the timber is sold, The area is then taxed in "fee except timber" [16] but still carries the same valuation as before. The same kind and quality of forest land in the same district, when held only as timber or as surface may be assessed at $15 to $30 an acre. On forested areas owned as surface the valuation is more likely to be lowered after cutting, especially if all merchantable material is cut. Light cullings and sometimes diameter-limit cuttings, which leave a fairly large number of merchantable trees, are not always followed by lower assessed valuations.

Timber tracts held only in surface or in timber afford a good index to the current valuation of timberland. Virgin or lightly culled timber is usually assessed higher than timber more heavily cut over. Accessibility is recognized in fixing valuations, but size of holding does not necessarily exert an influence. For example, a small tract in the midst of a large tract or adjacent to it usually will be assessed at the same rate as the large tract although the timber must be sold to the owner of the larger tract, usually at a low price, if it is sold at all.

Theoretically, values are placed according to the assessor's judgment and knowledge of general market conditions, but in reality the county board of equalization and review sets the final value so that usually the current year's assessments are merely copied from the books of the previous year, and no change is made until such time as the board decides to make a revaluation. Examination of the assessments of surface or timber rights on 50 tracts selected at random in the two counties showed that the average assessed valuation for virgin or lightly culled timber is $25 an acre, and for merchantable stands cut to a fairly high diameter limit, $15. Heavily cut-over, nonmerchantable stands are assessed at about $6 an acre in Nicholas County and $8 in Webster. Examination of a considerable number of transactions shows that there is no consistent relationship between assessed and sales values.

Judging from the trend of the tax rates and assessed valuation, the tax on timberland will continue to increase. Assessed valuations on forests containing merchantable timber were raised 25 to 100 per cent between 1915 and 1920. The valuation of cut-over land has remained constant since 1910. Tax rates have risen steadily in all the districts, the average annual increase during the last 17 years being about 8 cents per $100 of valuation.

The increase in the average amount of tax on each of the three classes of timberland is shown in Table 34.

TABLE 34.—*Tax per acre on timberland, average for all districts of Nicholas and Webster Counties in specified years*

Class of forest	1910	1915	1920	1925	1927
	Cents	*Cents*	*Cents*	*Cents*	*Cents*
Virgin and lightly culled	14	18	42	50	56
Merchantable second growth	8	11	25	30	34
Nonmerchantable cut over	6	7	12	14	16

[16] "Fee except timber" refers to the ownership of all the usual rights to land except the timber rights which refer to timber only.

Whether timberland will bear any greater share of the total tax burden in the future than in the past is a matter of conjecture. There is no doubt that the removal of the merchantable material from all the large tracts within the next 20 years will necessitate substantial increases in tax rates and probably also in assessed values, in order to meet the financial needs of the counties.

It is doubtful whether the assessed values on badly skinned forest land held in surface will be raised. The valuation of tracts on which the young timber is approaching merchantability probably will go higher. Such stands, when held in surface, are usually assessed now as bare land, but undoubtedly, under the steady pressure of need for additional revenue, cognizance will be taken of their increasing values.

OUTLINES OF AN ECONOMIC PROGRAM FOR THE NICHOLAS-WEBSTER SECTION

ECONOMIC PROGRAM FOR FARMING

Farming in Nicholas and Webster Counties eventually will be confined largely to the area that has been designated as agricultural. Outside this area the conditions are not suited to modern farming, and the investigators are convinced that people in general will not persistently follow the present type of farming in this nonagricultural zone.

The conditions under which farming in the agricultural zone will be practicable have been discussed.

For many years people will remain on farms in the nonagricultural zone. This is probably desirable. They have houses and outbuildings, garden plots, and a few head of stock, enabling them to live more comfortably here than they would if they were to sell their homes and move to town. Doubtless some young people will take up farming in the nonagricultural zone, but it is impossible to predict the trend for many years in the future.

The need for a larger degree of cooperation in the various agricultural undertakings is evident. At present there are practically no cooperative organizations. One of the most desirable forms of cooperative enterprise would be the formation of a cooperative motor-trucking association. The section is inadequately served by railroads, and many of the farm settlements are from 15 to 25 miles from a shipping point. The problem of hauling produce and supplies is therefore serious.

For example, it is almost out of the question for the farmers in the vicinity of Summersville to use lime on their fields because of the high cost of hauling it from Fenwick, 20 miles or more away. If the community in the vicinity of Summersville were to organize a cooperative motor-trucking association, the cost of hauling could probably be reduced to the point at which farmers could afford to use lime. The cooperative trucks could haul various kinds of produce from farm to market as well as haul supplies from their unloading point to the farm. The administration of such an organization would be simple as compared with many types of undertakings now handled by cooperative associations.

The agricultural extension and home demonstration work should be planned with a view to consolidating the agricultural industry in the agricultural zone. But farmers in the nonagricultural zone should

not be slighted; their precarious economic position is in itself a reason for giving them special attention. Whenever it can be shown that their land is not permanently suitable for farming, plans should be made for the best temporary use for farming or a combination including timber growing.

It would be helpful if the residents of tracts unsuited to profitable farming could be informed concerning opportunities for industrial or agricultural employment elsewhere (whenever conditions permit). This would enable those leaving the farms to seek employment under the most favorable conditions. A campaign to encourage farm abandonment is not suggested.

As stated previously, this study is an attempt to develop a long-time outlook. In order that a program of action be developed, there is need for the coordination of local activities by the organizations and the authorities interested in taxation, roads, schools, health, agriculture, and industry. Suggestions may come from the outside, but forward steps can be taken only by those who are directly interested in the welfare of their neighbors and themselves.

The local people will need to decide for themselves whether the interests of all will be best served by an improvement program for agriculture in a doubtful area or by the gradual abandonment of land not suited to farming. The situation is undoubtedly different in 1932 than it was in 1928, and changes will continue. Changing conditions make the task of planning difficult, but they also make planning all the more necessary.

PUBLIC ACQUISITION OF SCATTERED FARMS

It would be well if the State could purchase the scattered farms that are too few to support roads and schools, particularly where the maintenance of such facilities could be discontinued. These areas could then be blocked out wherever possible by further purchases from other forest-land owners in order to facilitate the organization of adequate fire protective measures and to provide for efficient forest management. The public should then be advised that settlers going into such tracts would not be provided with schools and roads. Settlement could be barred from State-owned land in any event. Later, when these tracts under proper forest management were again on a productive basis, small permanent wood-using industries, their capacity based upon the growth of the State-owned forests, could be introduced, as hereafter described. The land would again become populated, not by scattered settlers but by thriving communities gaining their entire livelihood from the products of the growing forests, and fully alive to the significance of this natural resource to their social and economic welfare.

COST OF GOVERNMENT

As eventually there probably will be fewer farms in Nicholas and Webster Counties and as the virgin timber resources are rapidly passing, it is time to make a special examination of the cost of carrying on local government. Probably it will be economical and feasible to consolidate certain county offices so that work of the various offices can be done with a smaller number of officials. This would effect a considerable saving to the taxpayers.

Fortunately, West Virginia has adopted the county-assessor system, but it is the practice to appoint deputy assessors to assist with the assessment. In these counties, as in most rural areas, the assessment is neither very accurate nor equitable and is unduly expensive.

FOREST INDUSTRIES

The manufacture of finished or semifinished products by permanent industries within the region, obtaining their raw material from the timberlands around them, would be of great benefit to the local communities. This would expand and stabilize the outlets for local produce and labor, increase the purchasing power of the community, and make possible a more satisfactory standard of living.

Before the old-growth timber is entirely removed it will be well to plan for the introduction of industries to utilize second-growth timber. Sawmills should be smaller than those now operating, because they should be based on the capacity of the forest to supply them continuously and permanently. Where supplies are obtained from large tracts under unified control, stationary band mills should be used rather than portable circular mills. The stands should be placed under management for sustained yield, and only a quantity of timber approximately equal to the annual growth should be cut in any one economic unit in a single year. Subsidiary industries, preferably under the same management, so as to insure efficient integration, should be established to utilize the sawmill by-products.

Economic disposal of small-sized products would mean closer utilization in the woods, resulting in less slash, and consequently less fire hazard than from present operations. The forest would also be kept more sanitary and would be less susceptible to damage by insects and disease. For example, manufacture of hardwood pulp would result in closer utilization of hardwood tops and large limbs in the woods and in the reclamation of much mill waste.

Lumber or logs, instead of being shipped out, would be manufactured locally into finished products. Stable industrial settlements, built around the local industries, would offer permanent markets for labor and agricultural products and would greatly benefit the community.

Many problems would arise in planning such permanent industries, particularly that of transportation. Where small materials are to be hauled, highways might be constructed on the grades of abandoned logging railroads, and trucks or tractors employed. The construction of flumes, or perhaps even of permanent, well-built dams, to carry or float pulpwood bolts or other small products, might be considered. In some cases it might even prove advisable to rebuild main-line railroads, using narrow-gage tracks and light steel.

The size of plant in a given locality would be governed by the quantity and availability of merchantable timber. The rugged character of the topography over most of the section would have to be considered in determining the availability of the timber and hence the most economic size of the unit.

The village of Cowen, for example, could be the site of a plant obtaining its supplies from some 40 to 60 farm tracts located within a radius of 5 to 10 miles. Let us assume, on the basis of the actual forest conditions in that locality, that an aggregate of 5,000 acres of

woodland is available and that 4,000 acres contain merchantable timber in the following classes:

	Acres
Virgin timber	1,000
Lightly culled timber	2,000
Merchantable second growth	1,000
Total merchantable	4,000
Nonmerchantable cutover	1,000

Before starting operations or deciding how the woodland should be handled, it would be wise to draw up a management plan providing for continuous, permanent production. An inventory of the quantity and kind of timber down to the smallest sizes, and a rough study of the annual growth should first be made. These might be supplemented by figures on growth obtained from the Appalachian Forest Experiment Station of the United States Forest Service.

Let it be assumed that a timber cruise shows a total of 41,000,000 board feet of timber 14 inches and upward in diameter breast high and that the percentages of the principal species are as follows: White oak, 30 per cent; red oak, 20; chestnut oak, 15; chestnut, 15; yellow poplar, 5; hemlock, 5; and miscellaneous, 10.

The average annual growth on the entire 5,000 acres is ascertained to be 433,000 board feet. A cutting cycle of 30 years, on the basis of the present stand and growth, can be adopted. A small-dimension mill and sawmill combined, cutting 500,000 feet annually, would be large enough.

Proper management of the contributing farm woodlands might be assured either by stipulating the kinds and sizes of trees desired or, better still, by going into the woods and marking specific trees for removal in accordance with silvicultural and economic considerations. The amount to be obtained in a given year from each tract would thus be determinable and the farmer would be paid only for the stipulated quantity of logs which he could cut and haul to the mill.

At the end of 30 years the first cutting of the 4,000 acres now merchantable will have been completed. A total stand of approximately 39,000,000 feet, consisting of 13,000,000 feet of new growth and 26,000,000 feet of old growing stock, will be left standing ready for the second cutting cycle. The woodlands will then be in a well-managed condition, capable of supporting the mill, which would now be cutting no more than the annual growth. As a result of good management, this growth may be expected to have increased to several times the amount at the start.

Lumber need not be the only product manufactured. Ties, squared stock, posts, and props might be milled to advantage. Poles and pulpwood might be produced whenever market conditions warranted their manufacture. Slabs, edgings, thinnings, and the lower grades of lumber could be converted most profitably into roughly sawn, small-dimension stock by means of additional but inexpensive equipment. Oak and chestnut stock could be shipped to furniture factories, and yellow poplar converted into squares for shelving and similar uses.

CONSOLIDATION AND MANAGEMENT OF FARM WOODLANDS

The development of agricultural operations on the better soils, and the accompanying consolidation of farms into larger units, is a step in the right direction. Many fine tracts of farm timberland still

remain in the section. Records of sales made by farmers show that the full value of stumpage is seldom, if ever, realized. Permanently established wood-using industries similar to those described will place the farmer in a more advantageous financial position with respect to his woodland and even his agricultural crops. He should attract and support such industries by foregoing the higher immediate but transitory income obtained by allowing the timber operator to "skin" his woodland in favor of the more moderate but continuous annual income derived from a community-building enterprise.

With the assurance of good future markets for woodland products, it will pay the farmer to consider carefully the manner of disposing of his timber. It is to his best interest to do his own cutting. In this way he can derive greater returns from his woodland. During the winter he can use his labor and teams in the woods. Furthermore, he can regulate the cutting according to desirable forestry practice, leaving the woods in good shape for later crops. The outside operator who buys the timber by the boundary, or by the acre, or perhaps by the thousand board feet, can not be depended upon to give the valuable young growth any consideration.

The farmer who goes no further than to cut his own products, hauling them as an individual to uncertain, shifting markets and accepting whatever prices are offered, may not be making the best of his opportunities. He can frequently achieve more through cooperative effort in some or all of the processes leading up to the final disposal of the finished products. By forming cooperative pools similar to those used in selling sheep or other farm products he would be able to reach wider markets and obtain better prices than are now offered. By shipping carload lots he would have the advantage of lower freight rates.

Pools would be advantageous particularly to those farmers whose woods are relatively far from the railroad, or are inaccessible, or are light and spotty. Tracts that could feasibly be operated by either large or small mills might also be handled to greater profit by cooperative enterprise.

By establishing connections with sawmills, veneer plants, furniture factories, and other wood-using industries through the efforts of the county agent and extension forester, farm woodland owners would be quoted definite prices for all grades of products. The estimated combined log output of the members of the pool, delivered at the track at any central shipping point, would then represent a stipulated value, and the farmers would feel assured in advance that they were employing their time and labor, and selling their product, to best advantage. Indeed, it would soon be learned, as it has been elsewhere, that more money could be realized in this way than by selling stumpage under present conditions.

The requirements of the wood-using industries would influence the cutting policy on the farm woodland in that only those trees that meet their specifications would be taken. As a result selective cutting and continuous production would be practiced, in contrast to the obsolete, wasteful "skinning" practices now prevalent.

CONSOLIDATION AND MANAGEMENT OF LARGE TRACTS

More than 80 per cent of the forest is located in large, unbroken tracts in the rougher, higher portions of the section. Ownership of many of these tracts is divided among a large number of individuals and

corporations. That the forests may be protected and managed more effectively, and because of the heavy investments necessary for the transport of forest products from such lands, it is desirable that they be consolidated into blocks, each of which should be either under single ownership or under coordinated management. Without such consolidation it will be difficult, in many instances, to insure that the lands will continue to be utilized for timber production.

CUTTING POLICIES

In selling timber from a large tract it is highly desirable to safeguard the owner's interests in its future value. Methods of cutting should be stipulated. Provision should be made in the contract for employing suitable fire-prevention measures, and for care in felling and skidding trees in order to reduce damage to young growth. Enforcing measures of this kind would entail no loss of time or money to either owner or operator. Lumbermen who operate in the national forests in the Appalachian region and elsewhere observe such regulations.

The operator who cuts on his own land should also be guided by the desire to protect the future value of his timber. The best use of the land will be realized only by allowing the more valuable trees to stand at least through their period of rapid growth. The range of minimum diameters for cutting conforming to the value and growth rate of the several species is indicated in the following list:

16 inches:
- Yellow poplar.
- Black walnut.
- Red oak.
- White ash.
- Black cherry.
- Cucumber magnolia.

14 inches:
- White oak.
- Chestnut oak.
- Basswood.
- Sugar maple.
- Hemlock.

12 inches:
- Hickory.
- Red maple.

10 inches:
- Black birch.
- Yellow birch.
- Beech.
- Butternut.

8 inches:
- Black locust.
- Black gum.

Species of lesser value should be cut to the smallest sizes practicable.

Rapid-growing trees should be grown for other products as well as for saw timber. Pulpwood is chief among these products; it offers perhaps the most permanent and satisfactory source of income for the future. This and other minor products may be obtained from intermediate cuttings made to improve the forest, as well as from the main operations.

The purpose in favoring certain species over others when cutting is to maintain or to increase the dominance of the most valuable species and consequently to render the site more productive. The truly selective cutting method is far better than the common practice of cutting out the best and leaving the poorest. The detrimental effects of the latter practice are evident throughout the cut-over forest areas of the southern Appalachian region.

In the oak-chestnut-hickory type, occurring chiefly on dry slopes and ridges, the oaks, hickories, and black cherry should be favored if they are already present. The blight-affected chestnut and the inferior species (black gum among others) should not be too heavily removed

at any one cutting; in fact, it is important that all cutting be light in order not to expose the vegetable mold to wind and sun unduly. Cutting may be heavier in that portion of the type located in the plateaulike glade area, where the greater dominance and better growth of the oaks and hickories on the rich soil and the level topography make the problem of improving the forest relatively simple.

In the oak-chestnut-poplar type it is best to favor the red and white oaks, yellow poplar, white ash, basswood, cucumber magnolia, and hickory, and the black walnut if it is present. Cutting may be heavier in this type wherever the present composition of the stand is poor enough to warrant.

PROTECTION FROM FIRE

The first and most important step in administration is protecting the forest from fire. To reduce and eventually to eliminate fire, the forest owners and the general public must cooperate fully with the State. Some owners cooperate now through the medium of forest-protective associations. Holders of small tracts adjacent to or within large forest areas should avail themselves of the extra protection afforded by association membership.

The farm woodland owner is most advantageously located to prevent and control fire in his neighborhood. Once his indifference to its effects is overcome, he can be depended upon to regard fire as a menace not only to his buildings and fences, but also to his woodland, whether it be mature timber, cut-over land, or restocking old fields. Furthermore, he will see that it is worth while to prevent and to check fires in the woods adjacent to his own, whether they be owned by fellow farmers or by large corporations.

The State and the individual counties should cooperate in a campaign of education and law enforcement to inculcate the idea of fire protection and to teach the proper use of fire. Then, when the laws against incendiarism, careless handling of brush and camp fires, and negligence of operators in failing to use fire-precautionary measures, are swiftly and effectively enforced, and when local sentiment can be depended on to support these laws by jury action, adequate protection from fire will be assured.

PUBLIC ASSISTANCE IN PRIVATE FORESTRY

Since so much of the Nation's wood supply comes from privately owned holdings, the private practice of forestry should be of much concern to the public. Most of the forest area in the region is capable of continuously producing good forest crops if it is properly managed. The State and Federal Governments can assist greatly by protecting the area from fire, from insect pests, from diseases, and from other destructive agencies; by extending credit for forestry operations; by giving technical advice and assistance; and by cooperating in management. One of the most effective ways in which the State can promote private forestry would be the adoption of a system of taxation under which taxes on forest lands would be commensurate with the productive capacity of those lands and under which the time of payment would be adjusted to correspond with the receipt of income from the forest.

Possibilities in extending long-time credit for forestry operations, particularly those of farm cooperatives, have not been studied thoroughly, nor have there been attempts to conduct cooperative

forestry operations. It may be that some form of cheap credit such as that provided for farming operations by the Federal farm loan act would be effective in financing cooperative forestry enterprises.

PUBLIC ACQUISITION OF FOREST LAND

Forest lands that are unsuited to private management because they can not support timber of rapid growth and high quality, or because of other unfavorable characteristics causing operating costs to be excessive or returns to be low, are not likely to be kept in a productive condition unless they are in public ownership. It is desirable for the public interest that a forest cover be maintained on most, if not all, of these lands, regardless of their value in producing commercial forest crops. Such forest cover would be of great benefit, both direct and indirect, to this and adjacent sections.

The forests at the highest elevations shelter the headwaters of many rivers and make the flow of the feeder streams more uniform. In other sections similar forests are being publicly acquired and placed under management wholly for the purpose of watershed protection.

Another possibility in public acquisition is that of providing recreation forests. The need for these is well recognized. In other States, large tracts are being purchased for this purpose. Forest areas that contain views, cliffs, caves, cascades, and excellent stands of virgin hardwoods which enhance the scenic values, are particularly adapted for recreational use.

The field observations indicate that there are several tracts in this territory that should be acquired by the public. A more intensive survey would be necessary to determine accurately the location, character, and extent of such land, but the following tracts may be suggested tentatively as suitable for acquisition:

The spruce forest at the headwaters of the Cherry, Gauley, and Elk Rivers is most important for watershed protection. Its extent in Nicholas and Webster Counties has been described.

The hardwood-forest areas along Point Mountain should be considered for their recreational value. (Fig. 11.) The rugged beauty of the territory along Point Mountain—the steep, deep valleys with the tumultuous, winding, silvery streams; the clear view of range after range as far as the eye can discern—is considerably enhanced by the continuous green mantle of forest growth, much of which is still in the virgin state although it is being cut over at the rate of 2,500 acres a year. The Elk River and its Back Fork furnish fine trout fishing, and the surrounding mountains offer good hunting and can be reached easily by automobile and railroad. A recreation reserve might comprise at least 40,000 acres from Webster Springs eastward along Point Mountain to beyond the county line, extending on both sides to Back Fork Mountain on the north and Gauley Divide on the south.

The Gauley Cliff and the Open Rock formations in central Nicholas County are of sufficient interest to be set aside for park purposes. Their forest cover enhances their value. The Open Rocks cover only a few hundred acres, but are near enough to the Gauley River to be a part of that territory. A belt of about 20,000 acres extending at least one-fourth mile on each side of the Gauley River from Persinger Ford to the western boundary of Nicholas County would form a substantial reserve easily accessible by automobile and offering suitable camping facilities.

Other localities furnishing excellent hunting (bear, deer, raccoon, and turkey) and fishing are found in the more inaccessible protection forests. For those hardy ones who wish to get back into the real wilderness such reservations would be very attractive.

THE PLACE OF SCHOOLS IN THE REGIONAL PROGRAM

It would be to the interest of the section to plan eventual curtailment of school and road expenditures in the part that is regarded as nonagricultural. But wherever in this section the population is fairly dense (and this will be the case in the vicinity of important logging operations) schools will be required regardless of the agricultural quality of the land. Practically no more land in this section will be

FIGURE 11.—A scene near Point Mountain. A recreational reserve in this locality would comprise inspirational scenery, the attractiveness of which is due largely to the sheltering mantle of green timber. (Elk River, several miles above Webster Springs)

cleared for agricultural use, consequently, when new schools are built, it should be kept in mind that their use probably will be temporary and expenditure should therefore be kept to a minimum.

Where there are only four or five farm families per school it would be advisable for the school districts, the county, and the State to purchase these farms in order to close the schools and eliminate the expense of their maintenance.

Where topographic conditions permit, it will be possible to consolidate several district schools into single schools although the rugged topography of the section will limit the extent to which this can take place. There are several creeks along which are scattered from three to a half dozen schools. To consolidate the small schools along a creek or ridge road would be advantageous. Wherever there are paved Class A roads the situation is favorable for consolidation. Such consolidated schools would provide a type of instruction superior

to that now offered, and their cost should not exceed the per capita cost of furnishing the present type of instruction.

There will be a permanent need for county high schools. There are now four in Nicholas and Webster Counties; these will be sufficient to meet the counties' needs for a long time. It would be better to give the existing county high schools larger financial support than to increase the number of such schools.

At present a liberal amount of State aid is given to the district schools. In general this should be continued. To whatever extent the State contribution relieves the local population of a part of the expense necessary to maintain schools of a given standard, it would appear to make it possible to farm on lands where the farmers could not make a living if such aid were not available. To whatever extent this is true, the granting of State aid defeats its own purpose; it tends to perpetuate the agricultural industry on lands that could not otherwise support the existing standard of living. Of course, this is not the case where the State contribution is employed wholly for the purpose of improving the quality of the local schools.

In an old section, as in Nicholas and Webster Counties, where the agriculture is static, particularly in the part designated as nonagricultural, one might well reason that the granting of State aid would tend not to stimulate agriculture but to retard its decline. It is a commonly accepted belief among many observers, however, that even if State aid for schools and roads were withdrawn from these marginal localities and the schools and roads should become inferior to those now maintained, people would persist in remaining there for a long time.

It is said further that since the people will persist in remaining it is necessary to retain State aid. Otherwise the inferior schools and roads would so react on the people as to render them a menace to the progress of surrounding communities.

The most effective means of maintaining a satisfactory standard of living within the section is redistribution of the population. This would be facilitated by so managing the forest resources as to achieve continuous, permanent production, thereby increasing the stability of communities within the section devoted to timber growing and by improvement in live stock production in other localities. Plans should be made to concentrate the expenditure of schools and road funds in localities that are capable of maintaining population on a reasonable standard of living by farming and forestry.

ROADS IN RELATION TO REGIONAL PLANNING

Such class A roads as are required in the section should be built by the State and should be constructed only where they will serve as links in the State highway system. As such they will be greatly needed to care for the cross-State traffic.

Certain county roads also serve as links of secondary importance in the State highway system and should receive some State aid. The West Virginia highway law should be revised to legalize financial aid in the construction and maintenance of county highways wherever they serve primarily the State class A highway system.

It is a common practice for the magisterial districts to bond themselves heavily in order to build roads of the class A type. This is rarely if ever advisable. In view of the facts that in most of the section

the virgin timber has been cut over and that the agricultural resources are less valuable than is commonly supposed, it is not inconceivable that some of the magisterial districts may be forced to default on their bonds.

The experience of many counties in the cut-over areas of the Middle West and the Northwest shows that high taxes in a cut-over area often lead to tax delinquency. In West Virginia there has been little tax delinquency thus far because the county and district expenditures have been low; the stand of virgin timber has been able heretofore to bear a heavy tax; and people have continued temporarily to pay fairly heavy taxes on denuded timber land for the coal which is supposed to underlie much of the territory.

In a cut-over area it is unwise to commit counties and magisterial districts to heavy expenditures. In such an area the tax base is very

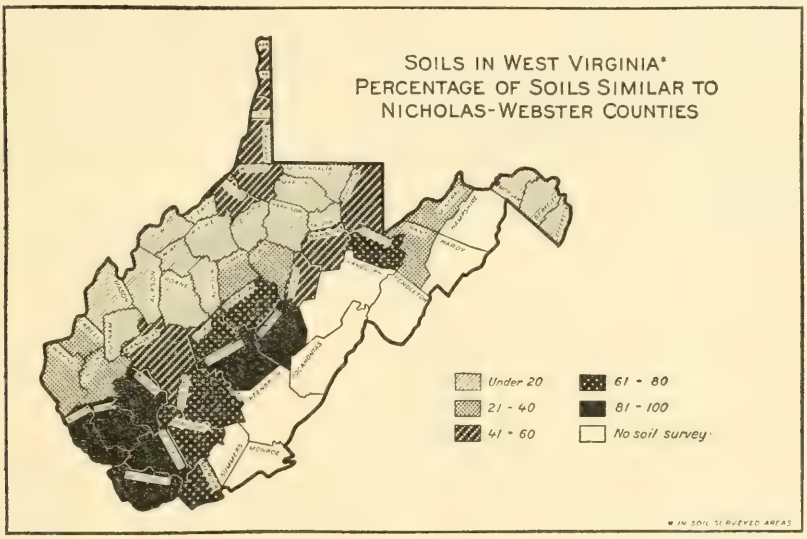

FIGURE 12.—The counties having soil characteristics similar to Nicholas and Webster are a part of the Appalachian highlands. Parts of unsurveyed counties are also in that region

unstable and will remain so until it is known how much of the tax the remaining farms and the cut-over woodland will bear. For that reason it is strongly recommended that the magisterial districts refrain from bonding themselves for construction of class A highways. A less expensive highway it is felt would serve the needs of the district adequately, and at the same time avoid a heavy bond issue, which may turn out to be more of a millstone than now seems commonly apparent.

EXTENT OF AREA IN WEST VIRGINIA TO WHICH RESULTS OF THIS STUDY PROBABLY APPLY

That the results of this inquiry apply in large measure to a considerable number of counties other than Nicholas and Webster, appears to be indicated by personal observation, analysis of census data, study of published geographical reports, computations based on soils maps, and examination of topographic maps. Figure 12 shows that 81 to 100

per cent of the soils in five of the chain of counties extending from Barbour to McDowell and Mingo are like those studied in Nicholas and Webster. Sixty-one to 80 per cent of the soils in six other counties—Fayette, Tucker, Clay, Braxton, and Raleigh—are like those of the Nicholas-Webster section. In 10 additional counties, 41 to 60 per cent of the soils are similar to those in Nicholas and Webster. Soil surveys of 47 neighboring counties have been made. The extent to which the results of this study apply to the larger adjacent section may be indicated roughly by the fact that of these 47 counties 15 have soils over 50 per cent of which are similar to those of Nicholas and Webster Counties. In counties of which the soils have not been surveyed it is to be supposed that a large proportion of the soil is like that of the counties for which soil-survey reports have been published.

However, the results of the study of land utilization in Nicholas and Webster Counties apply only in a general way to sections of similar characteristics. So far as the recommendation of specific measures is concerned the differences in transportation and market facilities; in distribution of farm areas; in the extent, character, and development of forest resources; and in other important factors may more than offset similarities in soil and topographic types. Separate study would be essential before specific measures could be framed for adoption.

It is believed that the broader aspects of public policy indicated in this bulletin would appear to apply to other large sections in the State.

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COTTON IMPROVEMENT THROUGH TYPE SELECTION

WITH SPECIAL REFERENCE TO THE ACALA VARIETY

BY

O. F. COOK

Principal Botanist, in Charge, Division of Cotton, Rubber and Other Tropical Plants, Bureau of Plant Industry

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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CONTENTS

	Page
General problems of selection in cotton	1
Need for continued selection	1
Precautions commonly overlooked	3
Selection to maintain adaptation	4
Nature and effects of selection	7
Breeding for novelties	9
Limitations of the pure-line theory	10
Effects of continued line breeding	12
Systems of selection defined and illustrated	13
Four systems of selection	13
Comparison of systems	14
Type selection and progeny selection	15
Simplified type selection	17
Recognizing and maintaining a superior type	18
Selection for preserving a type	21
Differences among type progenies	25
Significance of progeny drift	26
Cotton variations underlying the application of selection	28
Individual boll fluctuations	28
Abnormal variations of bolls	29
Uniformity an essential in cotton breeding	30
Visible and invisible characters	36
Earliness characters	39
Resistance to adverse conditions	44
Stress effects and growth disorders	48
Field conditions and precautions in selection	50
Choice of conditions for selection	50
Conditions for roguing	51
Precautions with select strains	52
Methods of testing progenies	53
Comparing type progenies in groups	55
Progeny comparisons in different places	57
Summary and conclusions	58
Literature cited	60

GENERAL PROBLEMS OF SELECTION IN COTTON

NEED FOR CONTINUED SELECTION

The problem of selection, as applied to the breeding and preservation of varieties of cotton, is more complex than current theories have recognized. Selection is the approved means of keeping a variety uniform and of maintaining its productiveness; methods of selection must be employed that will serve the intended purpose. Account must be taken of many more features or forms of diversity than have been considered formerly in order to preserve the essential characters of varieties by continued selection. Theories of selection must be reexamined, as these have been largely responsible for the methods of breeding used in the past. Changes in methods are suggested by facts that have come to light in recent years through the study of the varieties of cotton.

It is plain that the need of selection does not cease with the discovery and separation of a superior type of cotton any more than with a superior breed of animals. If selection is relaxed there is

no assurance that varieties will be maintained in a condition to produce cotton of good quality. Essentially the same problems arise in keeping up the plant varieties as with the breeds of animals, but less knowledge has been current regarding plants, and ideas of plant breeding are entertained which plainly would not apply to animals. More theories have been developed in connection with plant breeding, perhaps because the facts are less intimately known. Animals are dealt with as individuals, whereas plants are handled in bulk, as though individual and family characteristics were lacking.

Plant breeders are engaged largely in developing new varieties, whereas animal breeders are chiefly concerned with keeping up old and well-established breeds. New breeds of animals are seldom introduced, and then in most cases are imported from foreign countries where they have existed for long periods. Valuable breeds of animals have seldom been originated by crossing different species or by selecting peculiar individuals having strikingly unusual characteristics, which are the favorite methods among plant breeders for obtaining new kinds, although the "novelties" produced by these methods often are distinctly inferior to varieties already in use.

Stock raisers do not question that the best animals must be used in each generation, to keep up the standards of the good breeds. Cotton growers are led to believe that selection at intervals of several years is sufficient and that a "running out" of varieties after a few generations is natural and inevitable. After a bad season it is customary with many farmers to change the seed. Both of these popular beliefs among cotton growers are found to be erroneous, though widely and confidently accepted. Experience shows that selection must be applied continuously, and that varieties of cotton can thus be maintained for long periods. The notion of frequently changing the seed has been popularized by commercial breeders and seed merchants in advertising high-priced novelties.

In view of the limited quantities of seed that are bought by the farmers at fancy prices, there is little prospect of the cotton industry being supplied adequately through commercial channels, especially when catering to the supposed demand for novelties. In Texas 28 firms were reported in 1928 as producing registered, certified, and recertified cottonseed, more attention being given to the production of good seed than in most of the cotton-growing States, yet less than 5 per cent of the cotton acreage in Texas was planted with seed of this quality (*11*).[1]

An adequate selection or breeding system is needed for maintaining the seed stocks after superior varieties of cotton have been discovered and established in cultivation. The frequent introduction of new varieties is most decidedly not in the interest of improved production in the cotton industry. The search for new varieties is only a part of the problem of improvement, and it has no beneficial effect if good varieties are not maintained and utilized. Production that is based on inferior seed stocks is extremely wasteful and inefficient.

Methods and facilities for maintaining the production of good seed are essential to any substantial improvement of production in the

[1] Italic numbers in parentheses refer to Literature Cited, p. 60.

cotton industry, and study has been directed for several years to this problem. The lack of good seed is the underlying cause of the poor and irregular quality of much of the American cotton crop, and the multiplicity of varieties is largely responsible for the deficiency of seed supplies. Efforts toward improvement in other phases of production can not be really effective until adequate supplies of pure seed are established. Keeping up the seed stocks of superior varieties, rather than the creation of new types, is the essential breeding problem.

On account of the use of the fiber in textiles, a special need for uniformity is recognized in the breeding of cotton. The more uniform the plants can be made, the more uniform will be the fiber that they produce, the better the fiber will be adapted to manufacturing processes, and the greater its commercial value. Uniform fiber has less waste to be separated in spinning, and the cost of factory operation is lower, as the threads are more even and are broken less frequently in spinning or weaving. Finer threads can be made from uniform cotton, and the fabrics are stronger and more durable. The limited production and widely fluctuating prices of superior fiber have restricted its use. If regularly available at moderate prices, vastly larger quantities would be used than are now to be obtained. Substitutions of shorter or less uniform fiber are forced upon the manufacturers when the supplies of good fiber become too inadequate and uncertain and prices run so high as to become prohibitive. Cotton of the character that can be produced from the Acala variety would be used in enormous quantities if adequate supplies were assured.

Cotton still is the largest export product of the United States, and the low quality of the American cotton crop is a serious national handicap. The failure to establish a standardized production of good varieties of cotton in the United States not only invites injurious competition in foreign markets but limits American textile manufacturers to irregular and therefore inferior raw materials. In some of the competing countries greater precautions are being taken to supply cotton growers with good seed than in the United States. Not only the varieties and the quality of the seed, but the planting dates, the handling of the crop, and the clearing of the fields to destroy insect pests are matters that in some of the foreign countries are being prescribed and enforced by Government regulations. For example, the State domains in Egypt are utilized for the production of select seed which is distributed to the growers. In the silk industry of Japan all of the producers are supplied every year with hybrid silkworm eggs of standard quality from Government laboratories.

Several of the obstacles that stand in the way of a general improvement of quality in the American cotton crop have been summarized in a recent publication (*22*).

PRECAUTIONS COMMONLY OVERLOOKED

In the absence of a scientific understanding of the principles of selection and of the precautions that are necessary, most of the cotton growers are without any basis of practical judgment regarding the values of seed stocks and are frequently misled by newspaper reports

or statements of advertisers. In order to maintain good stocks of seed, continued selection, roguing, and testing of progenies and increased stocks are necessary, as well as complete isolation from other varieties. These operations must take account not only of numerous characters or differences among the plants but also of many facts of other kinds which may determine success or failure in this field of work. The objects to be attained, the material to be employed, the conditions required, the methods to be followed, and the ways of utilizing the results all need to be considered carefully.

Some of the difficulties in maintaining varieties of cotton undoubtedly are due to the failure to distinguish between different methods or systems of selection that have been applied. Distinctions are drawn by many writers between mass selection and individual selection, but the analysis of the problem must be carried further in order to reach a clear understanding of the facts, as developed in the breeding of cotton. Other forms or systems of selection may be recognized, which will facilitate the study of the breeding problems. A wide range of selective treatments is possible, from weeding out only the worst plants to saving only the best. Also, it is possible by way of error to discard the best type from a variety and to turn the course of selection to a defective or mediocre stock.

The name "type selection" has been used for a breeding method which is being applied to varieties of cotton, and especially to Acala, a variety grown extensively in organized communities of California and the Southwestern States. In some of the irrigated valleys whole communities or districts have adopted the plan of growing only one variety of cotton, so that the usual mixing and mongrelizing of seed stocks are avoided and an extensive production of pure seed is made possible.

In an organized community all the farmers can be supplied with seed of the same quality. This is a radical change from the condition that exists in unorganized communities, where each farmer feels at liberty to exercise his own preference or fancy in trying new kinds of cotton or in continuing to plant the local "gin-run" seed. Under the usual conditions of production the local stocks of seed are mixed by the machinery of the public gins, and plants of the different varieties are cross-pollinated in the fields.

The practical conclusion reached through the study of breeding problems is that seed improvement in the cotton industry should be essentially a community undertaking. Without the cooperation of his neighbors, the individual farmer seldom is able to keep up a pure stock seed, even for a few seasons. The biological problems of maintaining varieties attain a new importance when it is recognized that a system of adequate utilization of superior types can be developed through community production (*8*, *16*, *24*, *30*).

SELECTION TO MAINTAIN ADAPTATION

The assumption has been in the past that only a narrow range of adaptation was possible with varieties of cotton, so that a large number of varieties was supposed to be needed to meet the great diversity of soils and climatic conditions represented in the American Cotton Belt. It now appears that less confidence should be placed in this idea of close adaptation. Many test plantings have been made of the

same series of varieties in different regions, which leave no doubt that it is possible for the same variety to thrive and fructify under a wide range of conditions. Such tests have included several new varieties of upland cotton that were introduced from Mexico and Central America during the period of the boll-weevil invasion and tested in different parts of the country to determine their behavior. A notable extent of adaptation to different conditions has been shown in the Durango and Acala varieties in most of the cotton-growing regions of the United States. Not only were they found to be distinctly better adapted to the conditions of the irrigated valleys of the Southwest than eastern or Texas varieties, but also they gave excellent results under eastern conditions. The wider adaptation is significant as indicating that the present multiplicity of varieties is unnecessary.

If the same biological type can be retained with the same complex of characters, the adaptative qualifications of the stock should remain unimpaired and be capable of extensive utilization. By virtue of its adaptative qualifications the same biological type, if grown under different conditions, will show different characters, so that the same formal standards of recognition are not properly to be applied under all conditions. The conception of a biological type is to be distinguished from that of a formal complex of characters. If attempts are made to apply the same formal standards under all conditions, it is probable that mistakes will be made in selection and will result in a loss of the original biological type through shifting to a variant form. The danger of such unconscious shifting and substitution of types is indicated not only by the nature of the facts but by actual experience in cotton breeding.

Writers on heredity often refer to "merely fluctuating differences" as of no significance, but characters that are readily adjustable to conditions are not, for that reason, to be considered as less hereditary than characters that are not adjustable. The different degrees of adjustability of such characters may be very important from the standpoint of production, and the breeding experiments obviously must take practical account of the adjustment of the characters and range of adjustment to environmental conditions. Selection is not made most effectively unless the conditions are such as to test the environmental relation and allow the deficiencies of less vigorous plants or lines of descent to be recognized. Choice of the conditions of selection and of the places where the work of selection can be done to the best advantage should be recognized as a part of the practical breeding problem.

The requirement to be faced more definitely in breeding operations is to retain the adaptability of a variety. Not only uniformity but also productiveness is necessary and this includes the ability to behave normally under varied conditions. Even in cultivation in a single locality, a variety is exposed to a wide range of conditions during the growing season. Changes of moisture, temperature, and day-length conditions are generally to be met. In the southwestern irrigated valleys the soil and weather conditions are especially varied, so that a variety which proves to be generally adapted to the irrigated districts may also be of use in other parts of the Cotton Belt.

A wider use of the best varieties and a reduction of the number of varieties in use would be of general advantage in the production of cotton, as tending to increase the available quantities of uniform fiber. Also the use of the same variety in different regions of production makes possible replacement of seed stocks. The possibilities of such replacement need to be considered, not because the varieties are supposed to "run out," but because in some districts a nearly complete destruction of local seed stocks may occur in bad seasons, either as a result of adverse weather conditions or through heavy infestation of boll weevils or other insect pests. Floods, droughts, and untimely frosts may affect wide areas, and all of the good stocks of planting seed may be lost or badly depleted. Unless other supplies of good seed are then available, resort may be made to inferior stocks for replanting, so that the effects of such disasters are carried into other seasons.

Though most of the data given in this publication are drawn from the study of Acala cotton, the methods and precautions indicated by experience with this variety undoubtedly are applicable to other varieties and are equally necessary for maintaining the productiveness and uniformity of the seed stocks. The more extensively a variety is used, the more important is the problem of preserving the essential characters. The Acala stock undoubtedly could be split into many local varieties, as other stocks of upland cotton have been, but this seems less desirable than the preservation of such a stock in a condition of general adaptation, so that it can be utilized over a wider range of conditions.

The Acala variety was discovered in southern Mexico and acclimatized in Texas, where it soon became popular, but the usual mixing with other varieties took place, and the seed stocks were allowed to deteriorate, so that in a few years the buyers refused to pay premiums and the growers were disappointed. At that stage the variety might have been discarded completely if it had not been adopted in some of the irrigated districts of the Southwestern States. One-variety communities for Acala cotton were established, which made it possible for the seed to be kept pure. With supplies of pure seed available, the use of the variety extended later to all of the irrigated valleys. Nearly 900,000 acres of cotton were planted in the irrigated valleys in 1929, and a large proportion of this was Acala.

Though not confined to the irrigated districts, the Acala cotton in several respects is better adapted to southwestern conditions than any of the upland varieties that have been brought from the eastern Cotton Belt. In many formal tests it has been more productive than the Texas big-boll varieties, such as Mebane and Lone Star. Also the fiber is superior and has sold at a premium over ordinary short-staple cotton. The characters and history of the variety were given in a recent publication, which also contains a brief reference to the plan of type selection (*23*).

The larger series of experiments in different regions undoubtedly will be necessary to determine the extent of the practical applications that may be expected from the use of the type-selection method here indicated. It is believed that the features already observed in breeding Acala and other varieties of cotton afford sufficient reason for making such experiments, as well as for calling the attention of

breeders to some of the new aspects of the breeding problems. From the nature of the work, effective cooperation of investigators and practical breeders will be needed in the further development and use of the type method.

NATURE AND EFFECTS OF SELECTION

The functions of selection are commonly misunderstood and present critical questions in the field of breeding. The arguments and controversies regarding natural selection and evolution undoubtedly have tended to obscure thought in practical breeding work, where clearness is essential. Many writers refer to selection as though it were "an agency, capable of producing continuous and progressive racial changes"; but this general idea of an active power of changing characters, though forming the background of many discussions of selection, often proves misleading. The biological facts of selection need to be separated from the philosophical inferences.

Darwin's theory of selection as an agency for changing the characters of species was based on the assumption of blended inheritance, which has largely given place to the recognition of alternative inheritance, as shown by Mendelism. Even under the Darwinian theory, the effect as credited to selection was to preserve new variations from extinction, rather than to change the characters. The idea that selection created the characters and caused evolution to take place was not a necessary inference from the biological facts, though many of the earlier statements by Darwin, Huxley, and Wallace were misleading to philosophers and religious writers. It seemed a logical inference from Darwinism that evolution was merely an effect of environmental conditions, working through natural selection, and from such a generalization it was easily inferred that artificial selection could produce any desired changes in domestic breeds and varieties. Such misunderstandings not only have led to controversy but have interfered seriously with the extension of popular knowledge, regarding heredity and breeding (*5*).

Selection is a sifting process, not a mending or a making. By being rid of the poor plants we have more good ones. If all the plants are good the object of selection is fully attained. The breeder works entirely by elimination, his only direct action being upon the plants that are rejected and destroyed. The plants that are retained are not altered but merely allowed to reproduce.

A group effect of selection can be claimed, but not an individual effect as involved in changing a character. The species is changed, or the crop is improved in the sense that averages of certain qualities are raised. The group improvement is accomplished not by altering any of the characters but by substituting a different population through control of parentage. The expression "improvement by selection" may be used as a figure of speech, but "improvement through selection" accords better with the facts.

Selection readily becomes an agency of deterioration if wrongly applied. Grave injury may be done to a stock of plants by adverse selection. Though the breeder always looks for the best individuals, the course of selection must be chosen with caution, since even in careful breeding work there is always the possibility of selecting and propagating from individuals that appear to be good because they

have features that are specially desired, but that later may be found lacking in other essentials. Not only good characters but full combinations of good characters must be sought and maintained. The favorable effects of breeding from better individuals are reversed, and the group is impaired rapidly by breeding from mediocre or inferior individuals.

Selection may be applied in the hope of continually improving a variety, without being considered as a means of maintaining the variety. The idea of continued improvement no doubt is responsible to a considerable extent for the failure to preserve varieties. A continual succession of improvements is expected by believers in selection, while selection may be disregarded by those who believe in the stability of "pure lines." In either case the value of a superior type is not fully appreciated, and the attention necessary to preserve a superior type may be neglected.

A clear separation of the different purposes or functions of selection may not have appeared necessary in the past but now is in order, because in recent years many biologists have accepted the idea of Johannsen that selection as an agency of improvement ceases to have any effect as soon as the condition of a uniform pure line is attained. Some writers have believed that there are unit characters which are incapable of variation, while others have admitted slight changes of characters which might be preserved and increased in successive generations. In recent years many instances of gene mutation have been reported.

Selecting to maintain a variety is a different operation from what may be expected if the breeder is holding to the idea of continued improvement of a variety. As long as improvement is considered the primary object, the search is more likely to lead to the selection of off-type plants, so that the type is changed instead of being preserved. It is certain that most of the deviations from a type are not in the nature of improvements, though a few may present desirable characters. All the deviations need to be rejected, or at least separated and tested, instead of being substituted casually for the normal type of the variety.

For purposes of practical breeding it probably is desirable to discard, or at least to suspend, the idea of continued improvement of varieties in order to avoid the misleading implication that changes of characters are to be expected as a result of selection. There is no way to exclude or to set a limit to the possibility that desirable variations may occur which will further enhance the value of a select type. The search for such variations may be continued, but they need not be thought of as products of selection, in the sense of supposing that selection causes the variations to appear. From the nature of selection, the differences must arise in advance in order to be recognized and preserved by the breeder. The type may not be improved by continued selection, but selection must be maintained to keep the stock from deteriorating. Such selection may be considered as an intensive roguing process to prevent deterioration of the type. The object of ordinary roguing is to eliminate degenerate mutations before they can contaminate a seed stock, while the object of type selection is to avoid even those forms of weakness or degeneracy which are not readily perceptible, and which may be detected only by careful comparison and discrimination.

BREEDING FOR NOVELTIES

Breeders are attracted by novelties and often overlook the need of uniformity or other essential features; they also frequently change their basis of selection from season to season. Some varieties have been altered completely within a few years because the breeder slipped from one type to another, sometimes intentionally but often unconsciously. Though the dealer may continue to furnish seed under the same varietal name, the plants of the two stocks may appear entirely different when raised in adjoining rows. For practical purposes it is obviously more important to maintain a superior variety which may continue in use for a period of years than to develop a succession of short-lived varieties or strains, as the custom has been in the cotton industry. Many varieties are current for only a few years and pass out of use too rapidly for their true values to be determined, as this requires several seasons and many tests in different regions.

Lint percentages and individual plant yields are features to which attention often is directed almost exclusively, to the neglect of other characters of equal or greater importance from the standpoint of production. Many intelligent farmers believe that seed should be saved only from 5-lock bolls, while others are willing to pay fancy prices for seed from a high-yielding field with little regard to quality or mixture with other varieties.

Many varieties have been developed from plants with defective fruiting branches, defective bolls, or even defective fiber characters. The cluster varieties have the fruiting branches abnormally shortened and give an impression of fruitfulness, as the bolls are crowded together and show large masses of white cotton at harvest time; but cluster plants are often sterile, and no consistently productive cluster varieties have been developed. The clustered bolls are more difficult to pick, and the points of the divisions of the bolls are not well separated, so that the fingers of the pickers are more likely to suffer. Also more trash is likely to be picked with the cotton and the commercial grade lowered.

The breeder's psychology usually is very susceptible to the attraction of any feature that he may happen to notice on a plant that is larger or more productive than its neighbors, though the difference in size or yield may be only accidental. For instance, it may strike a breeder's fancy to select a plant that shows the first open boll, even without considering any other characters. New varieties in many cases are selected, advertised, and placed on the market solely on account of some slight peculiarity that serves as a "talking point," to furnish the breeder with a reason, or at least an argument, for introducing this new stock. Thus an abnormal form of boll with open sutures at the tip was selected a few years ago by a private breeder to develop an "improved" Acala cotton.

The nature of the abnormalities often favored by breeders may be understood by referring to the plates. Normal forms of bolls in Acala and Durango cotton are shown in Plates 1 to 14 and boll abnormalities of Acala cotton in Plates 15 to 19. The selection used by the private breeder is shown in Plate 18.

Careful comparison with a good stock of the original variety is seldom considered necessary by breeders of novelties, which often are placed on the market within a few seasons after the "discovery" is made of a productive plant with a peculiar character. Seed growers choose a good field in order to increase a new stock as rapidly as possible, without waiting to determine whether it really is better than the parent variety. Many such novelties are compared with older varieties at the State experiment stations, and in the great majority of cases no indications of superiority are found.

Errors by cotton breeders may be very costly to the producers, and every means of avoiding them should be applied, both in relation to the characters selected and to the methods of conducting the breeding operations. The precautions that really are necessary to maintain good stocks of seed are generally overlooked in the effort to supply the popular demand, which such advertising indirectly creates, for wonderful new kinds of cotton. Although it is far from the mind of the breeder to develop an inferior variety, yet this undoubtedly has been done very often in the field of cotton breeding.

The assumption usually is made that a selection from Acala or from any superior stock will have the good characters of the parent variety, plus any special feature that the breeder may have fancied in a plant that has varied from the stock. In other words it is assumed that variations in single characters occur frequently and can be picked out and increased for production without needing to be compared and tested anew in order to determine their adaptations to different conditions.

It is seen from experience given in this bulletin that such confidence in the value of new selections, even when made from the best varieties, is not warranted. Careful tests are required in each case where an individual selection is separated from an established pure-bred stock. Not only have all of the recognized departures from the type to be tested, but unrecognized departures from the type must be carefully avoided.

LIMITATIONS OF THE PURE-LINE THEORY

The functions of selection in maintaining varieties have not been appreciated, because many writers on plant breeding have assumed that seed stocks may be brought to a pure-line condition of complete uniformity and that such a condition, once attained, will continue indefinitely if no mixing of seed or crossing with other varieties takes place. All that seems necessary, from that viewpoint, is to isolate a pure stock, which then is expected to remain uniform without further attention. The problems of cotton breeding thus appear greatly simplified, as is shown in the following paragraph from a current textbook (*2, p. 393–394*):

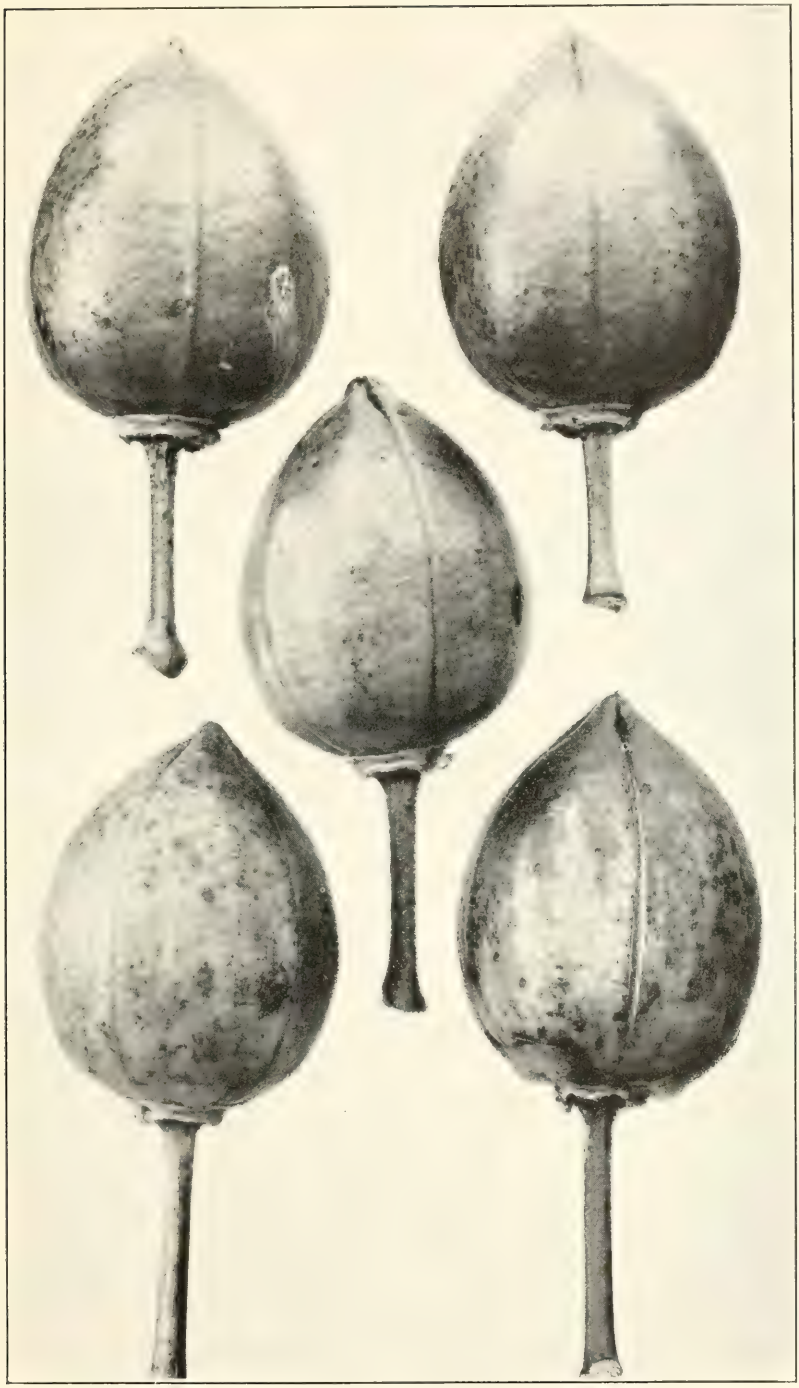
Breeding cotton. The most valuable parts of the cotton plant are long silky hairs attached to the seeds inside the cotton "boll" or seed pod. These hairs vary in number, length, and strength. It is desirable for most purposes (e. g., automobile tire casings) to have them as long, strong, and flexible as possible. Cotton in nature readily crosses, so that pure seed can be produced only by guarding against cross-pollination. The method of accomplishing this is both unique and effective. In certain isolated valleys of the arid southwestern United States cotton can be grown by irrigation and can easily be kept pure provided only one variety is grown in each valley. Growers in a valley agree

ACALA TYPE BOLLS

Typical forms of bolls and involucral bracts at Indio, Calif., October, 1921. (Natural size.)

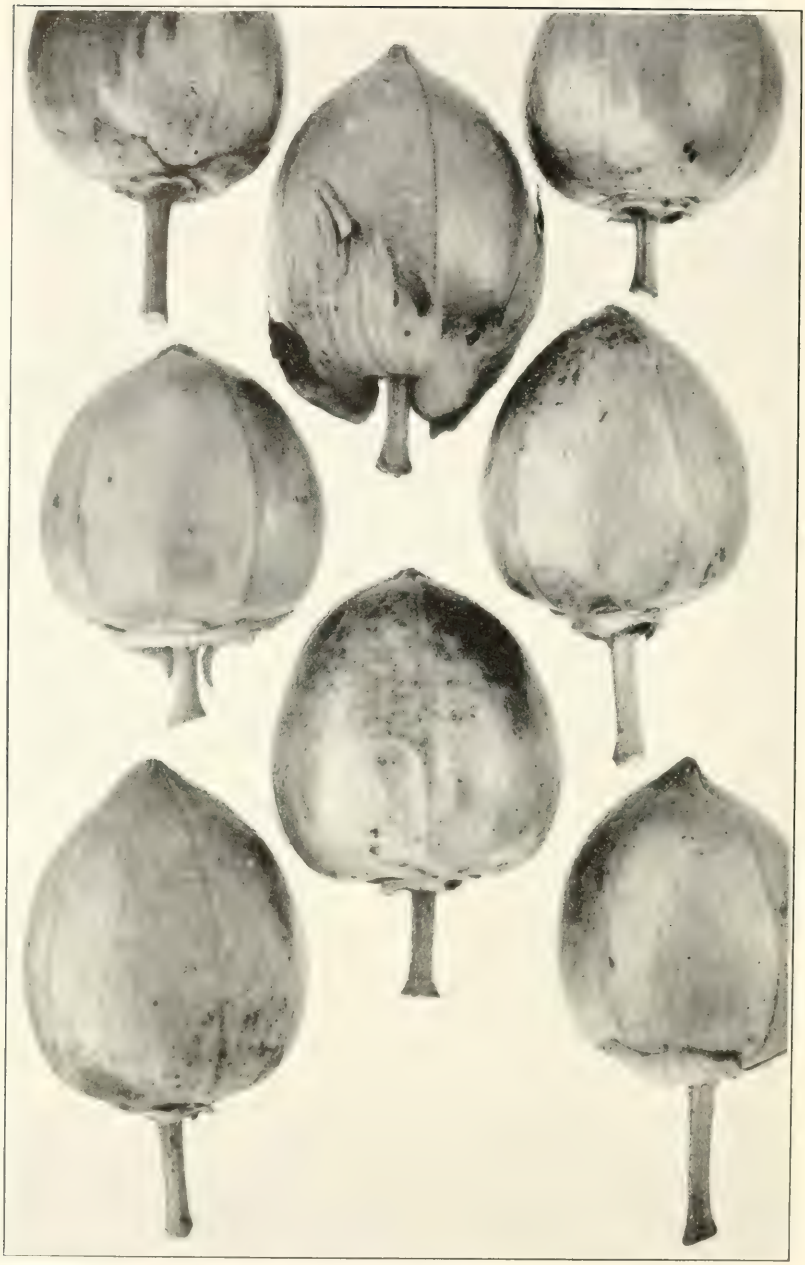
ACALA TYPE VARIATIONS

Illustrations of individual boll forms on plants of normal Acala type at Indio, Calif., November 23, 1925. The three upper bolls are from one plant, the lower bolls from another plant. (Natural size.)



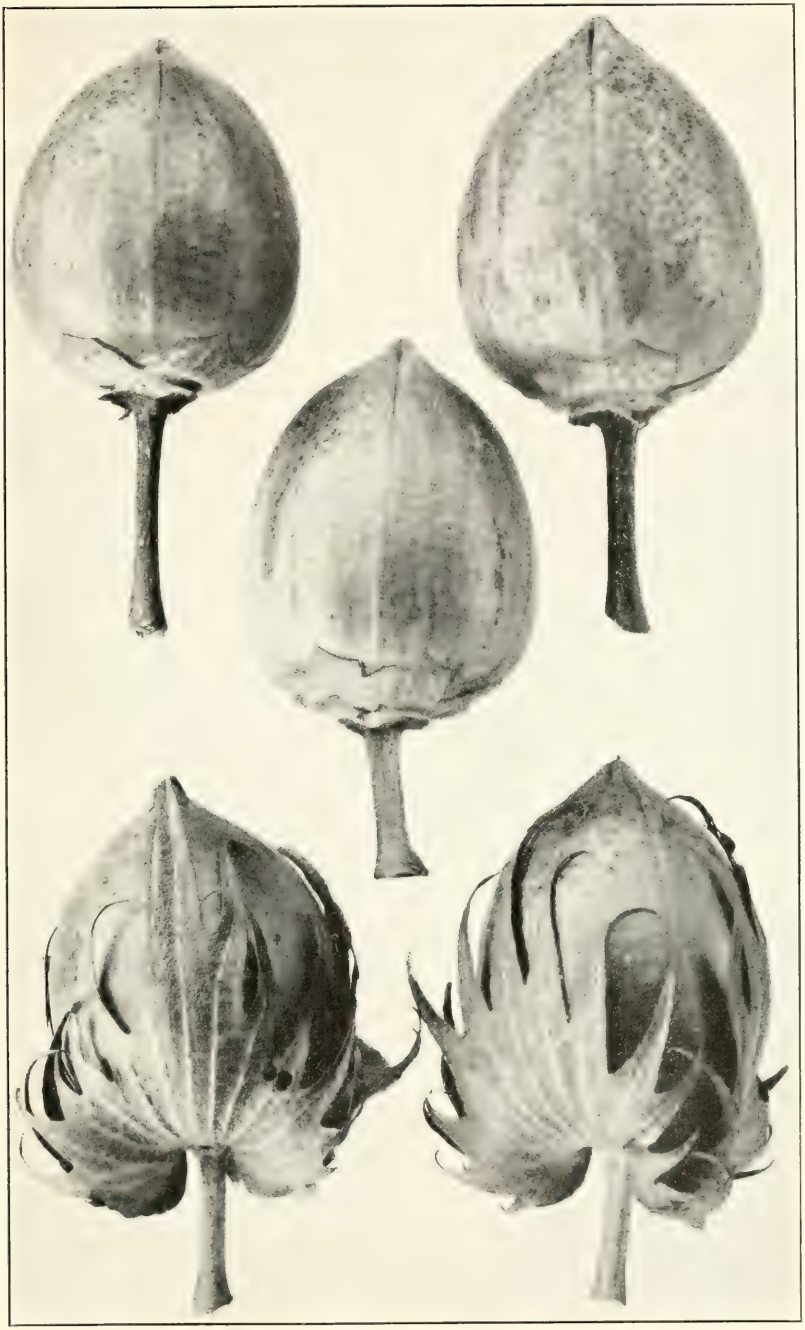
ACALA TYPE BOLLS FROM NEW MEXICO

Shape of normal bolls in Indio selection of Acala, grown at the New Mexico College of Agriculture, October, 1926. The outline is more sloping above and less rounded at the base than in the bolls grown at Indio. See Plates 1 and 2. (Natural size.)



ACALA LATE-SEASON BOLLS

Broader forms of bolls, more flattened underneath, are produced late in the season. Compare with Plate 6, showing bolls of the same plants developed earlier in the season and showing more oval forms. Also compare with Plate 5, showing Durango bolls produced in the same locality. (New Mexico College of Agriculture, State College, N. Mex.) (Nearly natural size.)

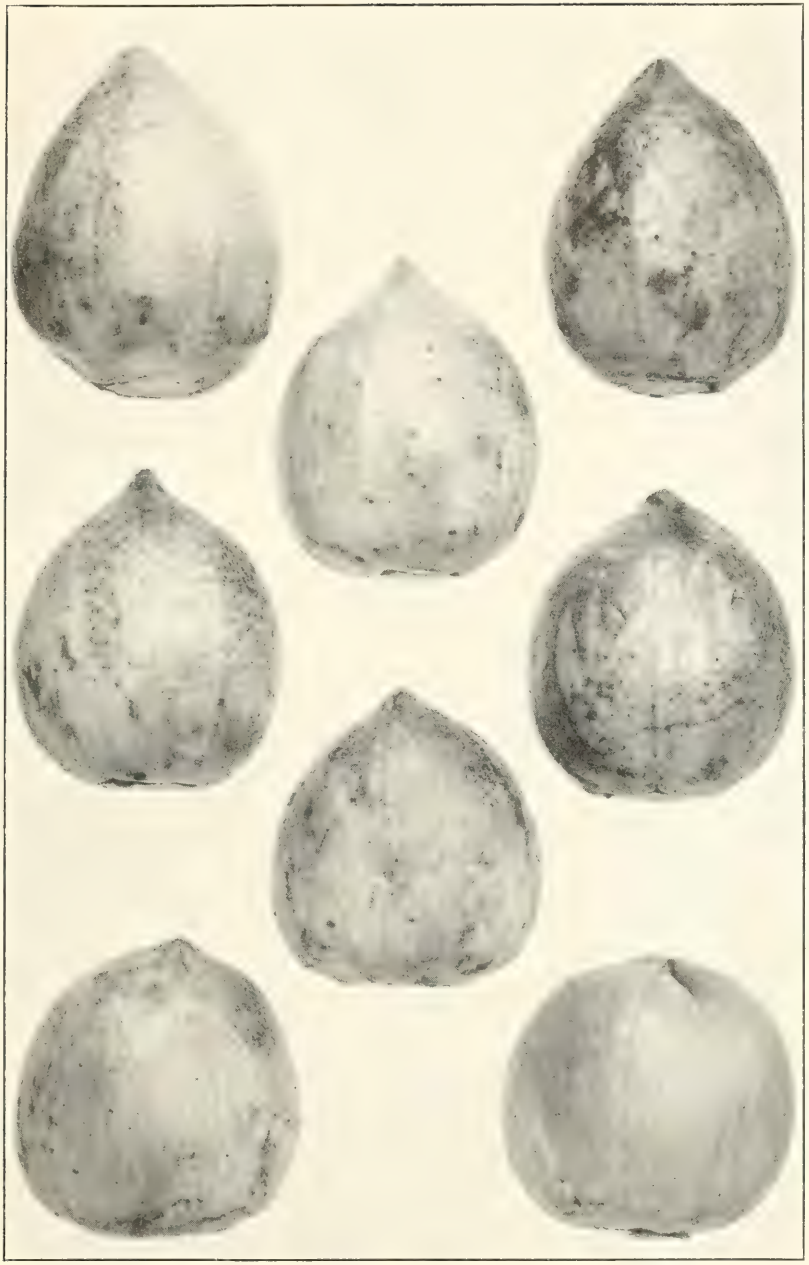


DURANGO COTTON BOLLS

Grown at the New Mexico College of Agriculture. These show close similarity to the Acala bolls grown in the same locality, Plate 4. Also to the variations of the Acala bolls grown in California, Plate 2. (Nearly natural size.)

ACALA TYPE BOLLS FROM NORTH CAROLINA

Acala bolls grown near Fayetteville, N. C., in 1926. The two upper bolls are of the oval normal type and the three lower ones a local Acala selection with blunt tip and flat base. (Nearly natural size.)

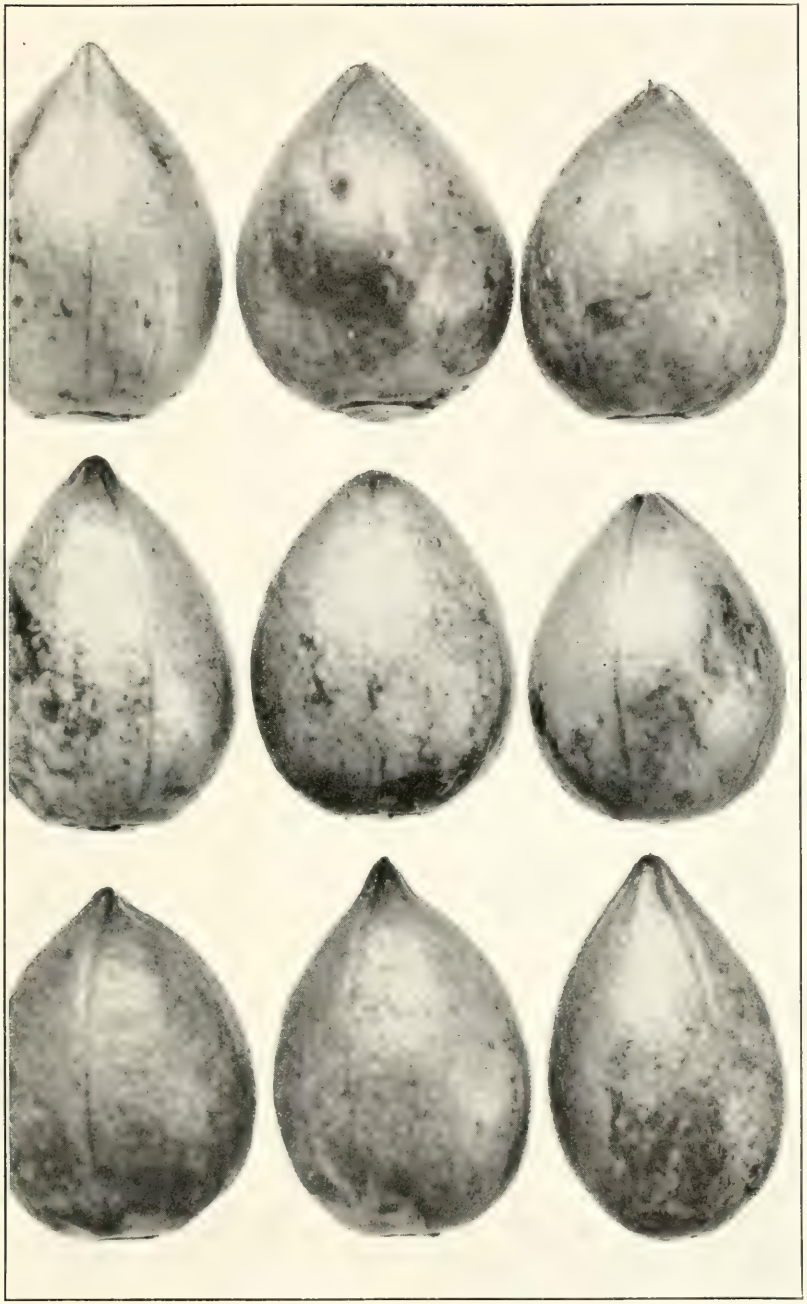


FORMS OF BOLLS OF ACALA COTTON

Bolls from several plants of Indio (Calif.) selection, grown at Fayetteville, N. C., showing the much broader forms of bolls, in comparison with the same stock grown at James Island, S. C., shown in Plate 9. (Photographed August 13, 1927. Nearly natural size.)

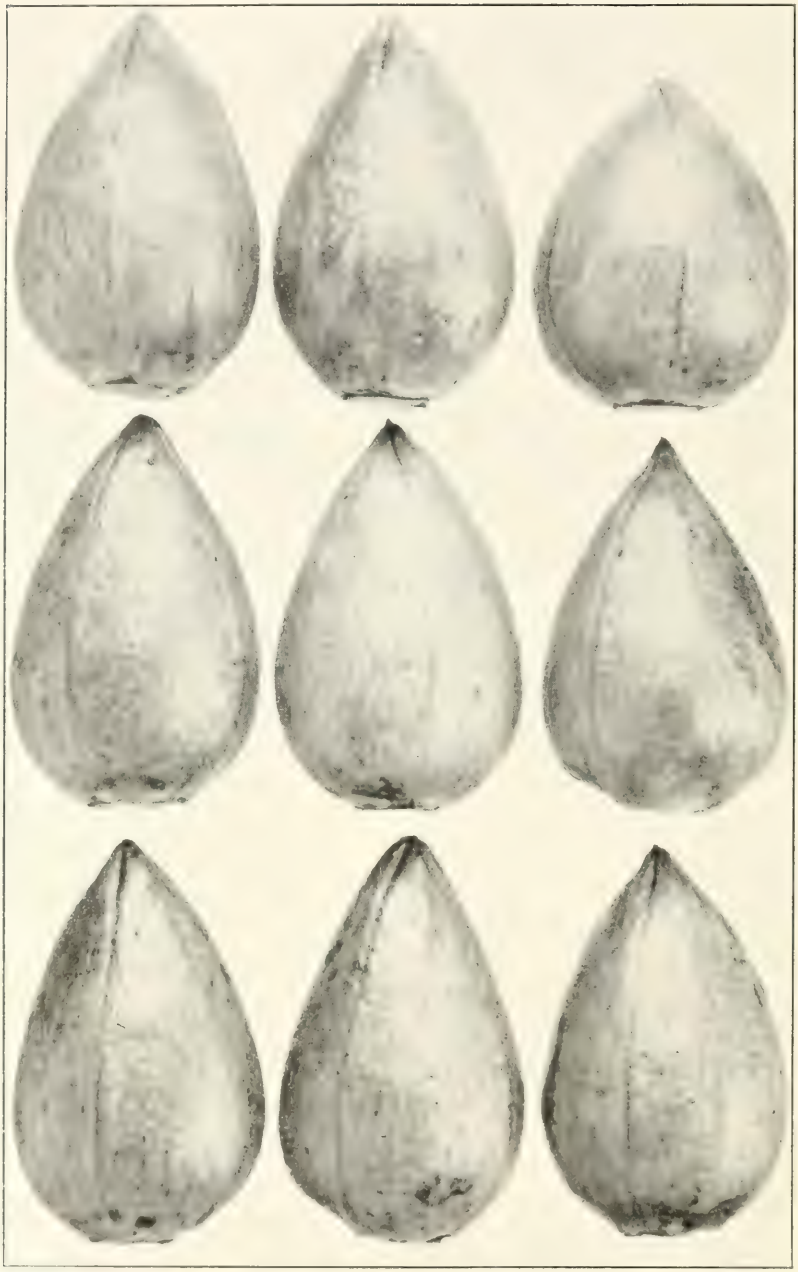
ACALA TYPE BOLLS FROM SOUTH CAROLINA

Bolls, involucral bracts, and calyx of Acala cotton, photographed at James Island, S. C., in August, 1928. Compare with Plate 10, showing the narrow Acala bolls produced at James Island in 1927. (Nearly natural size.)



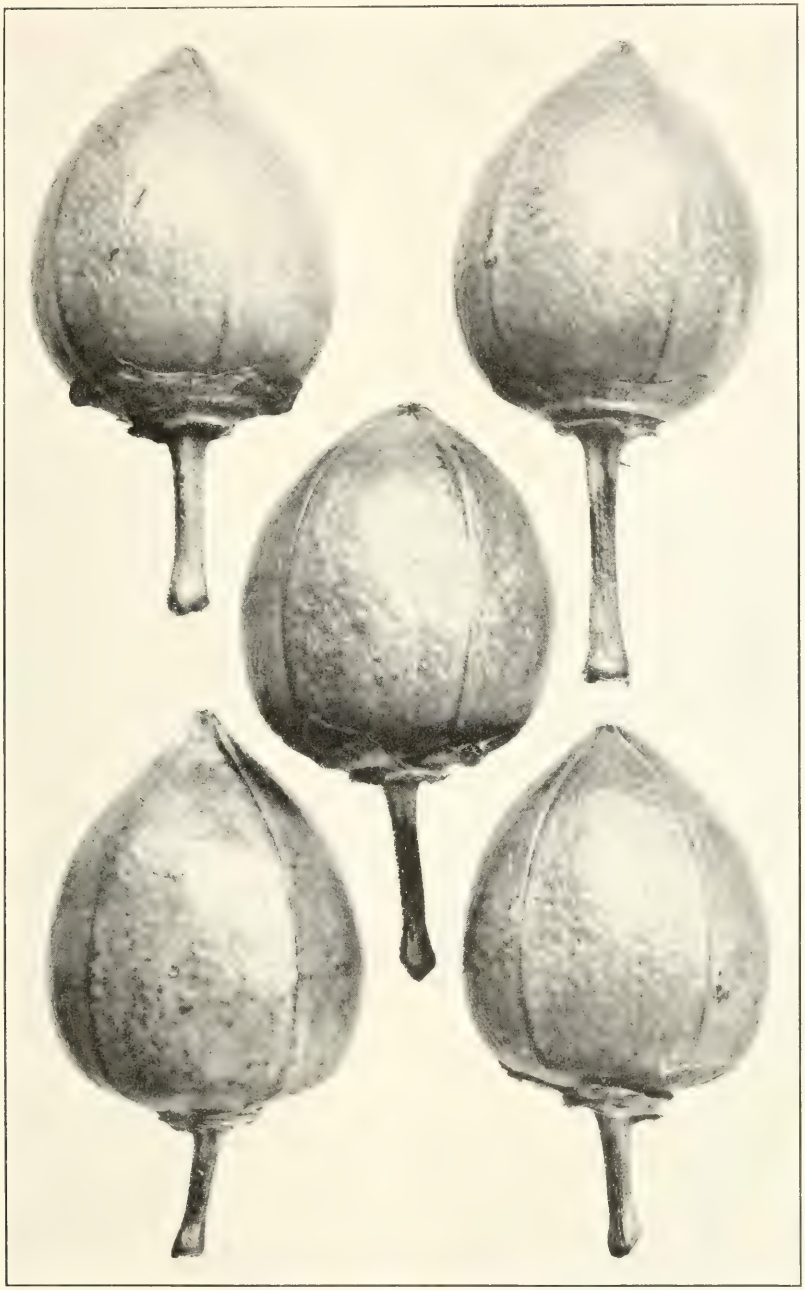
FORMS OF ACALA BOLLS

Bolls from three plants of Indio (Calif.) selection, grown at James Island, S. C., showing the narrow form of bolls. Compare with the same stock grown near Fayetteville, N. C., and at the New Mexico College of Agriculture, Plates 3 and 4. (Photographed August 27, 1927. Nearly natural size.)



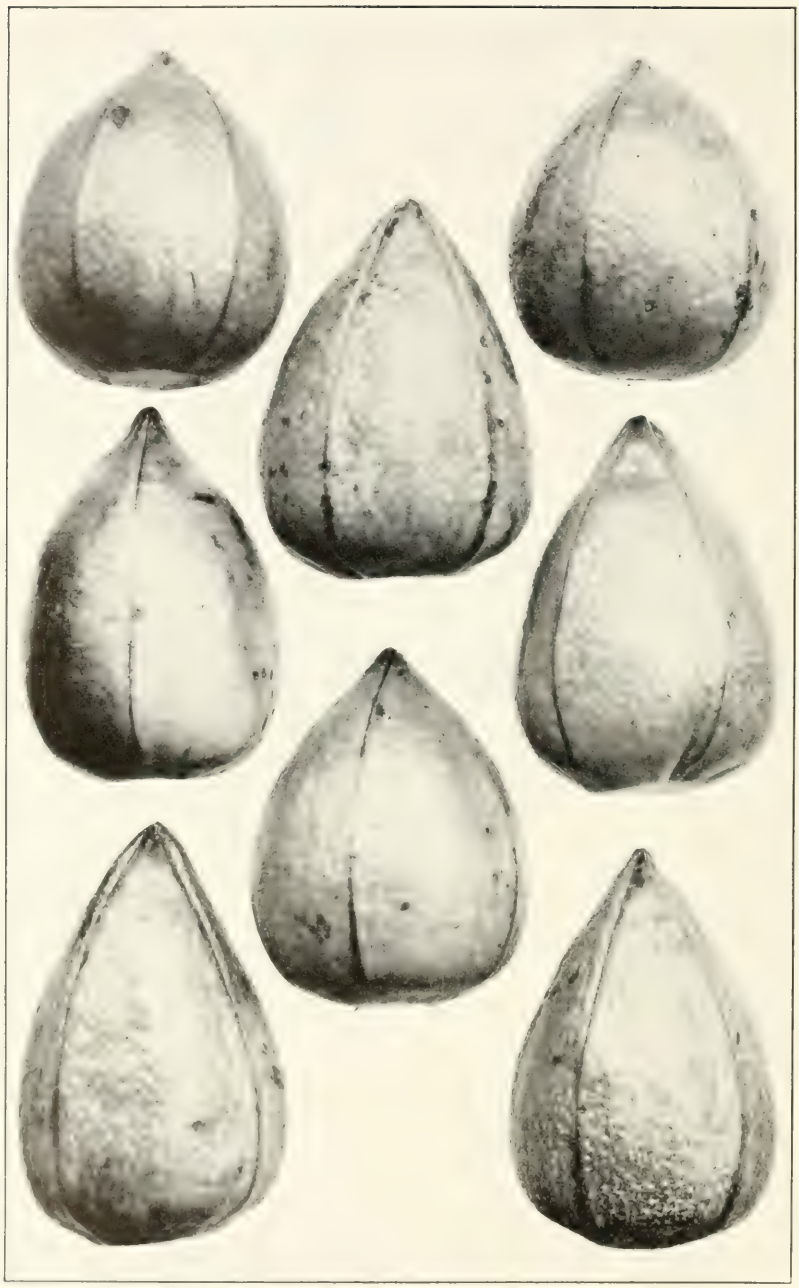
FORMS OF ACALA BOLLS

Bolls from three plants of Shafter (Calif.) selection, grown at James Island, S. C., showing narrow pointed bolls in comparison with Plate 14, which shows the same stock grown at Shafter, Calif., in the same season. (Photographed August 17, 1927. Nearly natural size.)



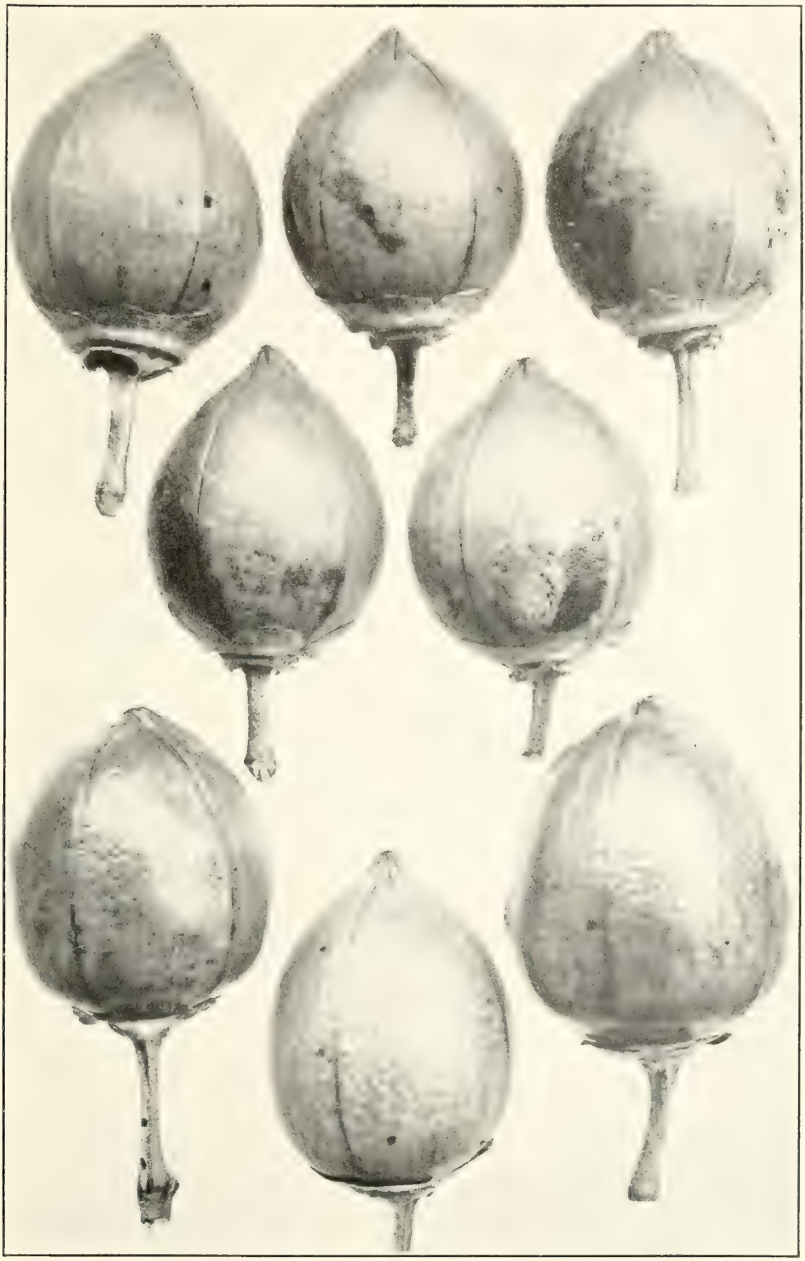
ACALA TYPE BOLLS FROM ARIZONA

Acala bolls grown in the Gila Valley of Arizona in 1924 from Indio (Calif.) seed. The upper two are typical; the lower three are from a different plant and are slightly broader and flatter at the base; also the surface is more remotely pitted. (Nearly natural size.)



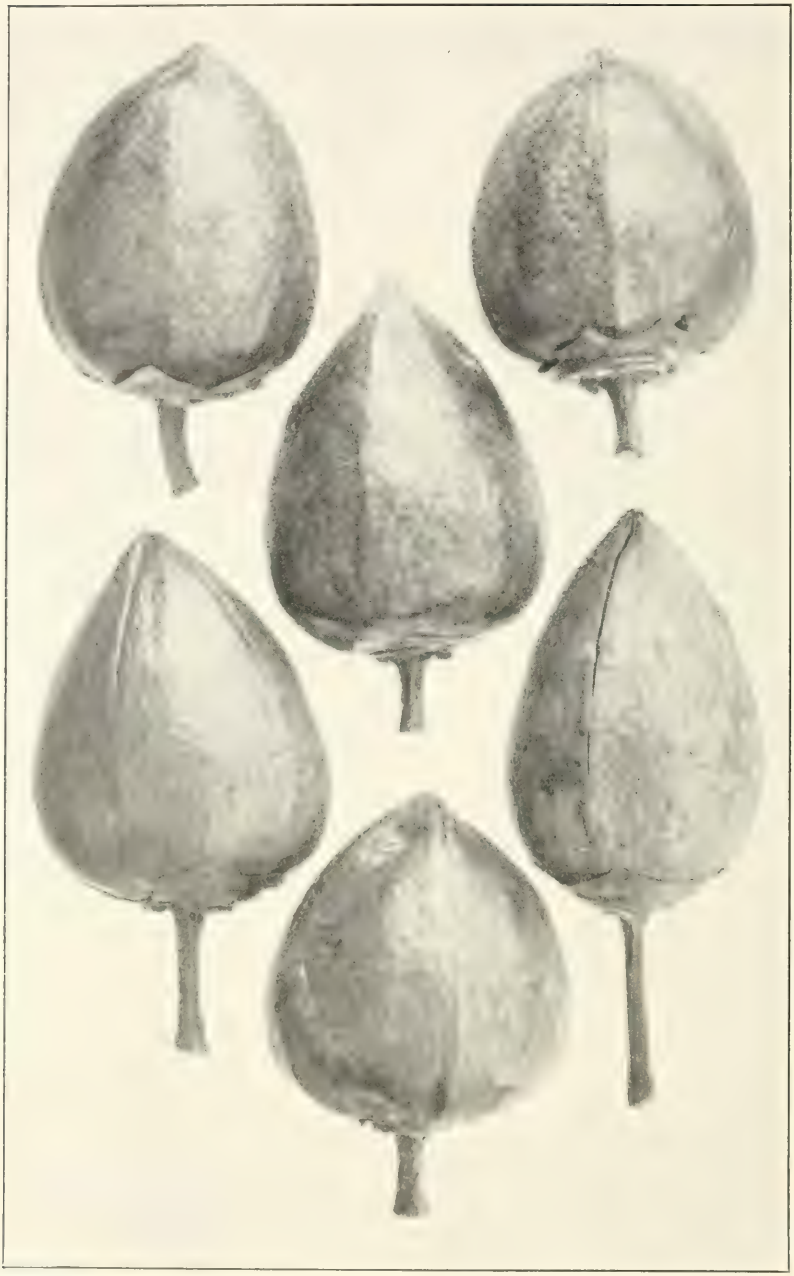
DIVERGENT BOLL FORM FROM ARIZONA

Bolls of type 4 mix-hunter plant grown in the Gila Valley of Arizona in 1924. Compare with the typical bolls (Pima) shown in Plates I and II; also to show the range of boll forms and surface sculpture on the same plant. (Nearly natural size.)



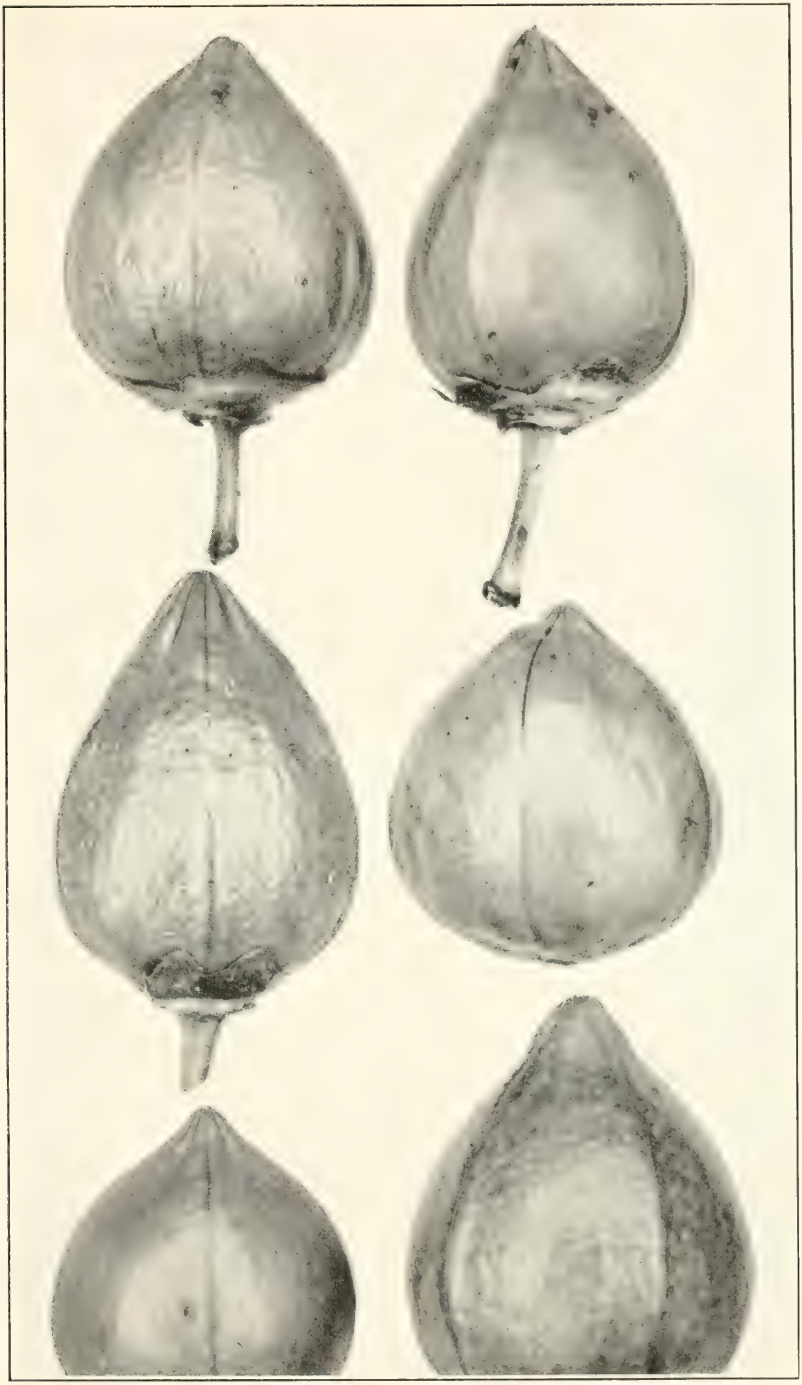
DIVERGENT BOLL FORMS FROM ARIZONA

Bolls from off-type plants in the Gila Valley of Arizona, 1924. Compare with typical bolls shown in Plate 11. The upper five bolls are from the same plant. The side bolls below are from a different plant, scarcely beyond the range of the type. The smaller boll at the bottom is from a normal plant. (Nearly natural size.)



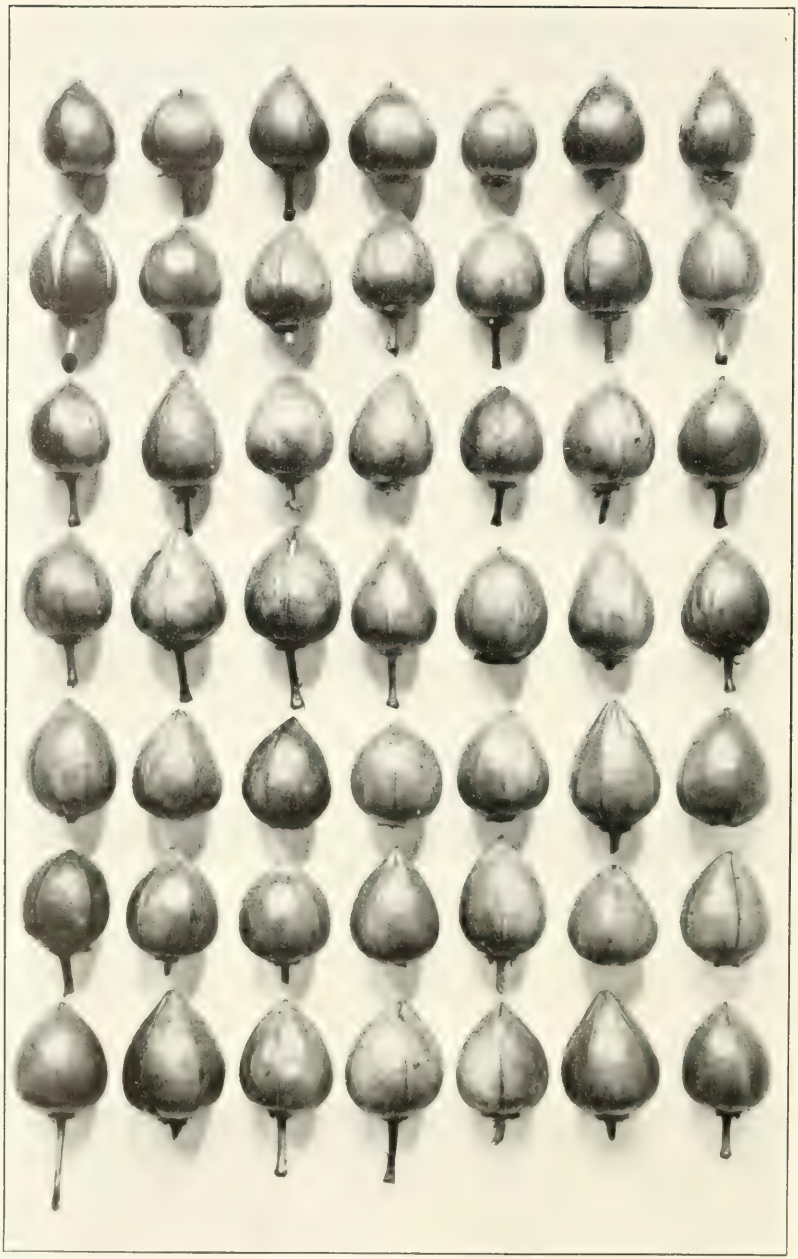
VARIATION IN ACALA BOLLS

Different forms of bolls in the Shafter (Calif.) selection, grown at Shafter in 1927. There are many rounded bolls and few with more triangular outlines than in the selection with typical bolls developed at Imbler, Oreg. Compare Plates 1 and 12. (Photographed December 12, 1927. Nearly natural size.)



ACALA OFF-TYPE BOLLS

Definite departures from the normal Acala boll type in the Shafter (Calif.) selection in 1928. Each pair of bolls is from the same plant, showing the range of individual boll variation. (Natural size.)

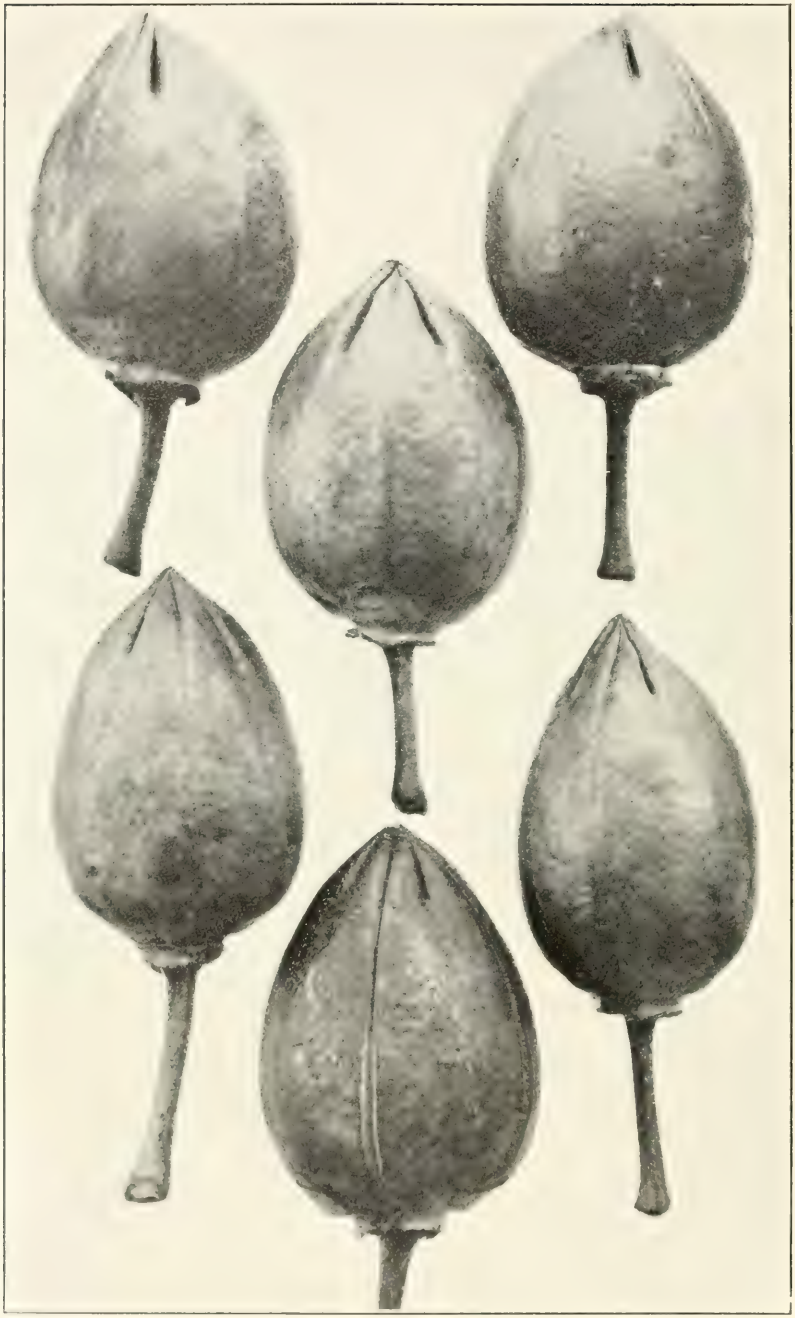


OFF-TYPE BOLL FORMS

Range of boll forms in a selection of Acala cotton at Shafter, Calif., in 1928. Note the general tendency to pyramidal form with sloping shoulders and flat base, in contrast with a few bolls of normal form with rounded shoulders and base. (About one-third natural size.)

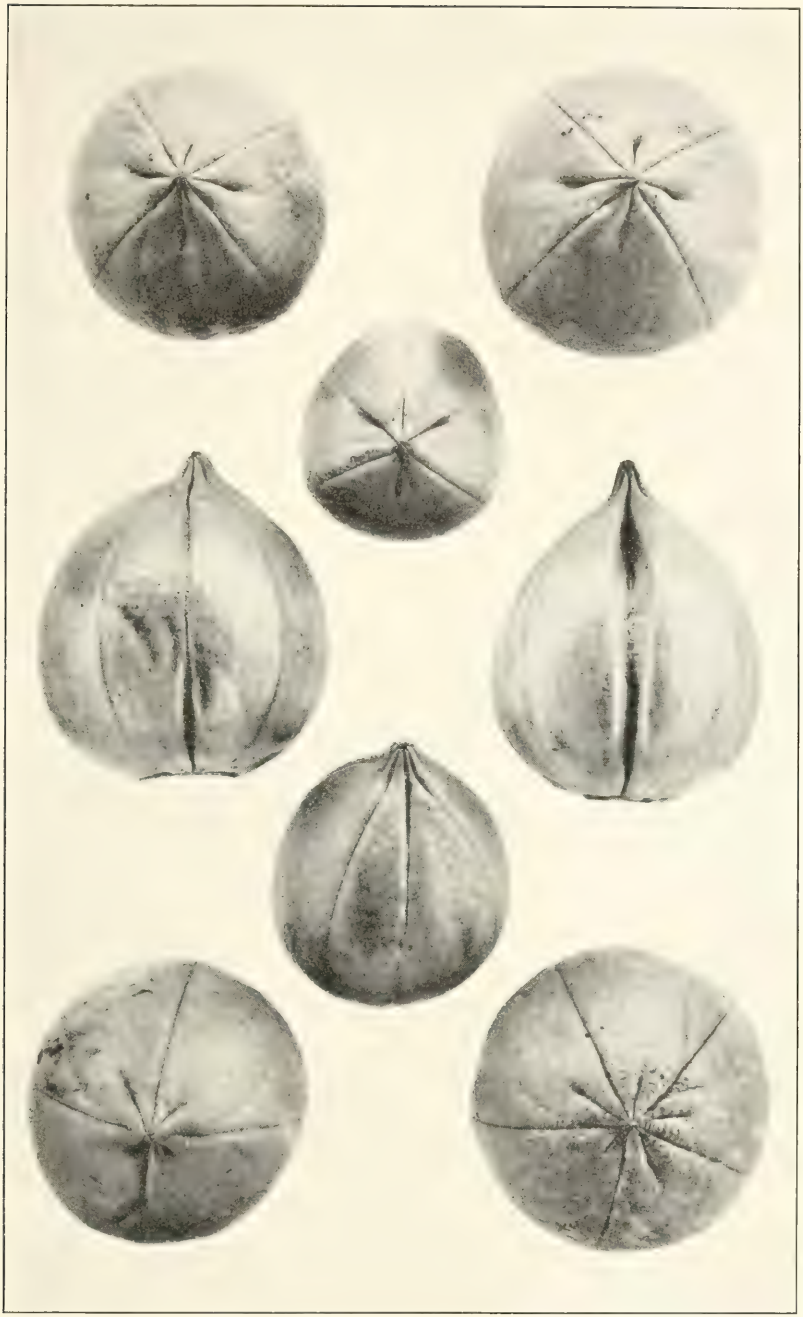
BOLLS OF AN ACALA ROGUE

A plant with small blunt-tipped round bolls found in a field of normal Acala cotton near Las Cruces, N. Mex., October, 1926. Compare with normal bolls of Acala, Plate 3, from the same district in the same season. (Nearly natural size.)



SELECTION OF ABNORMAL ACALA COTTON BOLLS

A variation of Acala bolls with the carpels not united at the ends, as shown by the deep grooves. This variation was used by a private breeder to form a new variety. (Las Cruces, N. Mex., 1926. Nearly natural size.)



ABNORMAL BOLLS WITH SUTURAL GROOVES

Variations in boll characters in a degenerate hybrid plant, showing pronounced examples of sutural grooves, in some cases extending the entire length of the bolls. Compare with Plate 18. (Nearly natural size.)

on a certain strain and then prevent by law the planting of any other kind. Selection for improved seed is then made in isolated breeding places until a suitable variety has been secured, and then only pure seed is sown in the valley. It remains pure merely because it has no chance to cross.

Many writers assume that species in nature are composed of uniform individuals and that diversity is due to hybridism or crossing with other species. Hence the inference is drawn that uniformity is a natural state of heredity and that the reproduction of uniform individuals will continue after a stock is purified from the results of crossing and then kept isolated. The mixing of different types undoubtedly is one of the causes of diversity and abnormality, while uniformity and stability of characters are sought at the opposite extreme by analysis of select groups into pure lines. The study of definitely contrasted characters in Mendelian hybrids no doubt has tended to establish a belief in pure lines as a stable condition of heredity.

Following this course of reasoning, an advantage may be expected from the repeated separation of a stock into individual lines of descent, as a continued approach to the ideal conditions of a pure and stable heredity. The tendency of the theory is to individualize the lines of descent as far as possible, on the assumption that this is desirable and assures a more stable condition. But in reality no advantage has been gained merely from the separation of the lines of descent in a group of plants, except as this facilitates selection. Pedigrees are records of descent, but other evidences of superiority are required to give such records a practical meaning. To go on making separations of individual lines, after a state of apparent uniformity has been reached, and without means of determining what differences may exist, is open to serious risk, especially if the work is done under favorable conditions for the growth of the plants. The choice of the best progeny becomes arbitrary, so that the more resistant lines of descent may be discarded, and others may be preserved which have less resistance to unfavorable conditions, with a consequent loss of adaptation.

The facts do not indicate that an absolute type can be maintained or will maintain itself simply by pure-line breeding, with selection relaxed or discontinued. The cotton plant affords unusual opportunities for putting the question of uniformity or diversity to a definite test. The plant is not too small to see readily nor too large to compare readily in most of its parts. Study is facilitated because flowering and fruiting of cotton are continued over periods of several weeks or months, in contrast with the many plants and trees where flowering and fruit setting are limited to a few days and in many cases to only a few hours. The general habits of the plants, the modes of branching, and the large number of differences that may be recognized in the leaves, flowers, and bolls are readily accessible to observation, and even the lint and seed characters are easily compared. In all of the characters that have received detailed study, tendencies to diversity have been found, even in stocks that have been selected carefully for many generations.

It need not be assumed that variations occurring in uniform pure-bred stocks necessarily represent new characters, since there are many of the so-called recessive characters which are inherited with-

out being brought into expression. Also, many of the differences that appear in hybrids and in mutations may be considered as reversions to older characters. Selective breeding tends to establish uniform expression of characters, but uniformity is never absolute. Even with vegetative propagation, variation is not entirely excluded. Many cases of bud mutation are known, and in some groups of plants such changes are not infrequent. The crazy top and other diversity diseases also show that the normal expression of the characters may be deranged in many ways during the development of the plant.

Among the equivalent structural members of the same plant body, differences are found which also seem to indicate that heredity is not stabilized. Not only is there a normal diversity of internode individuals to form the different organs, as required in the development of the plant, but the internodes of the same class often show slight individual differences (*15*).

Diversity instead of uniformity seems to be the condition of all natural species, as seen when sufficient study is given for one to become familiar with their characters. At least in the species and varieties of cotton notable diversities are always to be found, and it has not been possible by any refinement of the breeders' art to establish and maintain a condition of complete uniformity. Even in strains that have been self-fertilized for periods of years and have appeared very uniform, definite mutative changes of characters have occurred. It may be considered as a general rule or law of heredity that diversity tends to recur through mutations or by reappearance of recessive characters. As soon as selection is relaxed, the return to diversity becomes apparent.

EFFECTS OF CONTINUED LINE BREEDING

It is conceivable that a stock propagated for many generations on separate individual lines may become weak or unstable. The instability may be increased as the series of generations is extended. Selection may continue to remove all of the lines of descent in which a decline from standards of the type has been shown, either in external characters or in ability to produce, but other lines may then show weakness. The evidence of decline may be sought in plus and minus differences among members of the same types, as well as in characters that distinguish types or varieties from one another. Even with no appreciable changes in the external, visible characters, some members of a type may be stronger and more productive, while others lack vigor or bear little fruit.

A pedigree is not to be taken as a test or a proof of continued performance, but only as a promise or indication that good performance is possible. The highest parental standards are not likely to be maintained in all of the descendants. Even if selection is confined to the best individuals, some of the offspring are found to be inferior. Selection has to be continued in order to keep the stock from being diluted by the progenies of inferior individuals that would reduce the yield or impair the quality of the product.

The greatest and most obvious effect of selection is exerted at the first operation when a good type is separated from a diverse, degenerating stock. The more miscellaneous the stock, the greater the improvement by selection appears to be, when progenies of good

individuals are contrasted with a diversified general population. Notable improvements of yield, often to the extent of 20 or 30 per cent, may be made by suitable selections, as many unproductive individuals are usually to be found in mixed gin-run stocks. Such increases from selection are not to be expected in good stocks that are nearer to a state of uniformity. The theory of pure lines may be useful in helping to avoid unreasonable expectations if the assumption of natural uniformity and stability can be avoided.

No doubt the same extent of uniformity will not be attained with different plants when the phenomena are studied with sufficient care. As some writers have suggested, the pure-line theory may be more applicable to self-fertilized plants than to others. Essential differences may be found in the modes of inheritance in the various groups.

In upland varieties of cotton the stigma is much shorter than in the Egyptian and sea-island cottons, and on that account the upland varieties appear to be less exposed to crossing. On the other hand, greater susceptibility of upland cotton to fertilization by pollen of Egyptian cotton appears to be indicated by experiments conducted at Sacaton, Ariz., in 1920 by Kearney (*28, p. 9*), who makes the following statement:

> Plants of Pima were grown isolated in a plot of Acala and vice versa, and were left to natural pollination. The seeds from both sets of plants were planted the year following, and the Acala seeds yielded 28 per cent of hybrids while the Pima plants yielded only 12 per cent.

The extent of crossing between the two species no doubt is influenced by other features than the exserted stigma. On account of the longer style of the Egyptian cotton the pollen tubes must grow farther to reach the ovules. The pollen grains of the Egyptian cotton are much larger, and pollen tubes may grow faster, or some other factor may give an advantage in the competition with the pollen tubes of the upland cotton. This problem, however, is distinct from that of crossing among the plants of the same variety.

SYSTEMS OF SELECTION DEFINED AND ILLUSTRATED

FOUR SYSTEMS OF SELECTION

The following definitions and comparisons may serve in discriminating between type selection and other systems:

Mass selection is a process of reproducing from the better individuals of a stock. A separation may be made by discarding inferior individuals or by assembling good individuals, but the selected individuals have different characters, their progenies are not kept apart, and the resulting population continues to be diverse, even after many generations of mass selection.

Individual selection is a process of separating superior individuals and raising separate progenies from such individuals to start new populations. The effect is sometimes to produce uniform stocks and sometimes diverse stocks, depending on the characters and heredity of the individuals selected.

Progeny selection is a process of choice among progenies raised from superior individuals, progeny plantings being used as the basis of comparison and selection, instead of depending upon the

choice of the best individual plants. Progeny selection is more effective than individual selection, but may not result in uniform stocks. Progenies of different types may be included, or the type may be changed from year to year in an annual plant like cotton.

Type selection is a process in which the choice of individuals to furnish seed for progeny plantings is limited to a single type of plant, so that the progeny blocks are made as uniform as possible, to the limit of the breeder's ability to avoid deviations from the type. Also any variant individuals that can be detected are removed from progeny blocks and increase fields as a means of maintaining the uniformity of the stock.

COMPARISON OF SYSTEMS

Mass selection is the simple and gradual method of improvement that no doubt was followed, consciously or unconsciously, with all of the domesticated species before the more specialized methods were devised. Even among very primitive people, plants that attract favorable attention by special vigor, productiveness, or quality are likely to be saved for seed or propagated in other ways, though usually without being separated from each other or even from the general stock. As in natural selection, the poor forms are handicapped and the good are favored, but the selections are not of the same type. Continued mass selection raises the average of a population by lessening the representation of inferior lines of descent, but may not reduce to any great extent the diversity of the stock. Plants with inferior characters continue to appear, and crossing keeps the inferior characters current in the stock, even though seed be saved only from good individuals.

Individual selection is based on the recognition of single superior plants. The breeder trusts to his ability to pick out the best plant in a field or a breeding block, saves the seed of this individual, and makes a separate small planting for increase as a seed stock. A uniform progeny may be obtained in this way, and the next year a field planting may be made. The system of individual selection was used effectively for many years with sea-island cotton on the coast islands of South Carolina and Georgia.

In progeny selection the breeder does not rely upon his ability to choose the best plant, but selects many good plants and the following year compares their progenies, planted in adjacent rows. The precaution of comparing the progenies of the selected individuals affords a better means of determining the characters or differences that may exist in a series of selections and also of comparing and determining the uniformity of the selections, to the end of choosing the best progeny for increase as a seed stock. Undoubtedly progeny selection is a step in advance of individual selection, but it has practical limitations from the standpoint of establishing and maintaining the uniformity of a seed stock.

Type selection follows the methods of individual and progeny selection, but with further precautions of adhering to a single type in the selection and progeny work and of roguing the progeny blocks and increase fields. Roguing is applied to remove the off-type plants that continue to appear, even in the stocks that are bred with greatest care, or in progenies produced by self-fertilization.

Progeny blocks that are not restricted to the same type of plants do not produce uniform seed stocks unless artificial self-pollination is applied. Making a collection of good individuals, but of different types, and raising their progenies together, is not essentially different from mass selection. Much crossing may take place between the adjacent rows of cotton, so that with different types represented in the progeny blocks the crossing and mongrelizing of the stocks is continued as in ordinary fields. Good progenies may be adjacent to selections with divergent characters and may be thoroughly contaminated by cross-pollination if many bees or other insects are at work in the fields. Such diversity is excluded from the progeny blocks under the type system.

If plants that diverge from the type are selected intentionally for further study or testing, they should not be designated or numbered as progenies, but only as selections, and these are not to be grown in the progeny blocks or in adjacent rows, but in isolated plantings. The two projects of preserving an existing type and of breeding novelties need to be handled separately.

It is much more important to maintain a desirable type from year to year than it is to try to find a novelty that will be so definitely better than the type as to justify a substitution. The possibility of finding a valuable new type of plant is not to be excluded from the breeder's hopes, but the responsible breeder should moderate his zeal for novelties. At least he should appreciate the necessity for testing thoroughly each new form and for testing it in many localities before exploiting it as a commercial seed stock, and the need for maintaining by continued and careful selection any form which is to be used for practical production purposes.

TYPE SELECTION AND PROGENY SELECTION

Adherence to a type simplifies breeding operations, as a more definite object is presented. The object is not to discover new characters or to establish new combinations of characters, but only to preserve the combination of characters already existing in the type—not incompatible or doubtful combinations, as in many hybrids, but combinations already well balanced and adjusted to each other. So many characters are involved in a type that selection for each one of them would not be feasible, but the entire combination is selected by keeping within the type. The special advantage of the type system is to maintain the selection of many characters at once.

The selection of the best individuals of the type serves to keep up the full expression of the desirable characters, though it is not to be expected that all of the desirable characters will be brought to full expression in any one place or in any one set of conditions. Characters of special value from the standpoint of adaptation to particular conditions need to be specially guarded, and selecting must be done under conditions where differences in these characters can be shown. Otherwise there is danger that exclusive consideration of one character or of a few characters may result in loss or impairment of other characters and restrict the range of adaptation.

The highest-yielding plants in one season may excel by reason of some particular character, while a different season requires excellence in another character. The breeder may suppose that he is selecting

consistently for the same character (yield), but different characters may be responsible for good yields in different seasons or in different soils. The type may be guarded the better by being selected for different characters, but special precautions are necessary to avoid departure from the type, as explained later. The selection of the same type under the varied conditions is a way of assuring the continued possession of all of the desirable characters. In this respect type selection is analogous to natural selection.

Type selection, especially if applied under different conditions, may be considered as an extension of natural selection, since it is not merely analytical and exclusive, in the sense of isolating particular characters, but is a system for maintaining the full series of type characters by checking against possible losses of desirable characters in some of the lines of descent. The problem is not to be solved by applying an artificial standard, but by learning to recognize the actual forms of the plants. In practice, the type is not established nor standardized by assuming that the plants ought to show certain characters under all conditions, but by observation and familiarity with plants of the same stock grown in different places. The ability to recognize the same type of plant, even under widely different conditions of growth, is essential to useful breeding work by the method of type selection.

The advantage to be expected from comparisons of type progenies is the assurance of maintaining a more uniform stock, but there is no reason to expect that yields will continue to be increased, or even that high yields will be maintained, unless special precautions are taken. The usual comparison of progenies or of small increase blocks affords little basis for judgment regarding the various characters that are expressed in the yields. The effects of slight differences of soil or moisture conditions are such as greatly to complicate the task of progeny selection. Usually there is little ground for choosing a particular progeny as the best, in a series raised from plants that were carefully selected for adherence to the same type. A field of such progenies appears uniform, and the yield differences between the rows may be only accidental. Progenies with low yields may be rejected as a precaution, without attempting to determine whether the apparent deficiencies are real; but even that ground of choice is lacking among the progenies that yield well.

As often shown in field plantings, row variations as large as 30 or 50 per cent may occur, which have no genetic significance.

Maintaining a seed stock on the basis of a series of progenies is a different system in several respects from taking a single progeny for increase and rejecting the others. Taking only one progeny for increase involves the risk of definitely impairing the true type of the variety by losing some of its essential characters. Selection for uniformity alone may result in a loss of productiveness. Even if the external features of the type appear to have been retained, the range of adaptation may be narrowed, to the detriment of production. Apparently there is no practical way of assuring the preservation of all of the desirable characters of a type where selection in each generation is limited to a single progeny or to a single locality. At least it can be seen that such an undertaking is essentially more

difficult and precarious than maintaining a superior type as a group of progenies that can be tested in different places.

The danger involved in the restriction of seed stock to a single progeny is greater where the progeny plantings are made under the very favorable conditions that are commonly preferred for breeding work. The best conditions usually are considered necessary for breeding experiments, in order to raise the most thrifty and productive plants and show to full advantage the desirable characters of the variety, as well as to increase the seed stocks as rapidly as possible. But with breeding confined to the most favorable places, the differences that affect the resistance of the plants to adverse conditions are not brought into expression, and the weakness of a select stock may not become apparent.

SIMPLIFIED TYPE SELECTION

Type selection may be practiced without the precautions of progeny selection. If the breeder has sufficient skill, accuracy, and regularity of perception always to recognize his type, it is possible to maintain a high-quality seed stock, even though the selected plants are not picked separately or the seed planted in progeny rows. A method of type selection, very simple and yet very effective, was used for many years by the late Alexander Mebane in the breeding of the Triumph variety of Texas big-boll cotton, at Lockhart, Tex. The practical feasibility of the method was demonstrated by maintaining a very uniform variety of cotton through the long period in which the work was continued by Mr. Mebane. The same stock was selected on the same farm for about 30 years.

The method followed was to select the planting seed for the next season from the best and most productive plants. Enough seed was selected each year to plant the entire farm, with an adequate reserve for replanting. The selections were made carefully, only the plants that were notably more productive than their neighbors being considered. Each of these productive individuals was observed closely to detect any deviation from the variety in plant characters. Then the lint and seeds were examined, to make sure that the fiber was of normal length, strength, and abundance and that the fuzz of the seeds was not colored, abnormal, nor deficient. The accepted plants were marked by drawing a furrow with the foot, and the cotton was harvested at once by a careful picker.

Such an operation might be mistaken for mass selection if it were not known to be directed to a single type of plant, but this is a vital difference. The usual practice among cotton breeders has been to carry a miscellaneous collection of types in their breeding blocks. Obviously, the value of the field work depends upon the ability of the breeder to apply the necessary discrimination of the type. Such skill was evidenced in Mr. Mebane's case by the great uniformity of his increase stock. The fields of Triumph cotton at Lockhart were carefully inspected on two occasions in 1906 and 1907. The entire acreage was gone over consecutively, and very few rogues or aberrant plants were detected (*6*, *18*).

The system applied by Mr. Mebane did not include the precaution of separating and comparing the progenies of the select individuals.

Nevertheless it included another selective feature which the usual progeny methods do not provide. The operation of choosing from the more productive plants of his type was repeated each year and had the effect of a continued selection for normal behavior and productiveness under the varied seasonal conditions. On account of the wide range of climatic variations in Texas, different adaptive characters are brought into expression, as shown by the contrasting behavior of plants of the same stock when grown for successive seasons in the same field. Hence it can be understood that an annual reselection of the best plants of the type may be very important in maintaining the vigor, fruitfulness, and uniformity of a seed stock.

The principal advantage of growing the progenies in adjacent rows is that the breeder can test and check his judgment regarding the type and eliminate the progenies that give any indication of weakness or divergence. Hence the use of progenies seems advisable, as an additional precaution in type selection and to facilitate the comparison and recognition of the uniformity in seed stocks. It is important to have the assurance that the work of breeding is well done. Practically uniform fields of cotton will result when the type that is being selected is carried correctly and accurately by the breeder and the progenies are planted together, though slight differences are still to be found when well-selected progenies are closely and carefully compared. The progeny-row comparisons are needed especially for the study of the lint and seed characters, where slight differences may be important and yet are difficult to establish. The separate ginning and planting of the progenies are the only additional operations required in handling type selections as progenies.

RECOGNIZING AND MAINTAINING A SUPERIOR TYPE

It is obviously important to know how to choose the type of plant that is to serve as the standard of selection in a variety of cotton, since this largely determines the value of the subsequent breeding operations. The recognition and preservation of a superior type already in existence are the practical alternatives to the theory of forming synthetic types of plants by hybrid combinations of characters.

In view of the number of characters to be considered, it is seen that the choice of a new type is not a simple or arbitrary act. Efforts have been made with cotton, as with other plants, to establish varieties on a basis of artificial standards expressed numerically on score cards. Such schemes have not produced practical results, probably because many of the score-card features were of little importance and made the problems of selection too complicated to be followed. From the nature of the facts, explicit directions are hardly to be given for recognizing a superior type of cotton.

The recognition of a type as potentially valuable is merely provisional and preliminary to the careful comparing and testing that are necessary before a definite assurance can be reached that the new type has a practical value. In the case of the Acala cotton, it happened that only a single plant was seen at the locality in southern Mexico, where the existence of the new cotton was first recognized as having characters that might render it useful in the United States. Before this provisional judgment could be verified, it was necessary

to send another expedition to the cotton-growing districts of southern Mexico for stocks of seed and afterwards to determine the adaptability of the new cotton to conditions in Texas by several seasons of acclimatization and selection (*4*, *23*).

A stock of seed that came from the town of Acala, in the State of Chiapas, behaved best under Texas conditions and furnished the progenies that later were increased to the scale of commercial planting. It was not until adequate stocks of acclimatized select seed were available that it was possible to make thorough and conclusive comparisons with other varieties under regular field conditions. Such tests left no doubt of the ability of the new stocks to yield well and to produce fiber of excellent quality under boll-weevil conditions in Texas.

The choice of a superior type in the Acala cotton followed a similar experience with Durango cotton, which had been introduced and acclimatized from Mexico a few years in advance of the Acala. A superior type was recognized in the Durango cotton at Del Rio, Tex., in 1907, and developed to the scale of commercial production in California. The first field of Durango cotton in California was planted in 1911 in the Imperial Valley near El Centro.

The possibility of finding other good types in the Durango stock was also considered when the superior type was first recognized. The plantings of the original stock of seed in Texas were continued in the following seasons to see if any other types of plant could be found of as great value as that which had been chosen, or of greater value. In the course of two or three years several recurrences of the superior type were obtained, but no other type was found which appeared to be more promising or even to be equal to the type that had been selected. Thousands of plants were inspected carefully in the search for a better type, and progenies were grown from all individuals that appeared notable in any desirable respect.

The same precautions were observed in the breeding of the Acala cotton from the original seed stock obtained in Mexico. The first plantings in Texas, in 1907, were at Victoria, Kerrville, and Del Rio. A superior type of Acala was recognized at San Antonio in 1909, and a field planting of this stock was made at Waco in 1911. After the good type had been distinguished, other types with characters of equal quality and promise were sought but were not found. During the years that the variety has been cultivated, great numbers of off-type plants have been observed and studied without any being found that were better than the normal type in productiveness or quality of lint. Only a few were found that were even approximately equal to the normal type.

Some of the off-type plants were very productive and attracted favorable attention, especially those of the cluster habit with bolls crowded together on the short branches. As in other varieties, the cluster plants often appear very prolific and may yield well under favorable conditions. But under stress conditions the cluster plants suffer more, and cluster variations of Acala have appeared to be more susceptible to shedding. Hence it has seemed necessary to avoid cluster variations in the Acala stock. Reasons for considering the cluster character as abnormal were given in earlier publications (*12*, *32*).

The type recognized as superior in the seed stock from Acala had early and prolific plants of an erect, pyramidal form with large oval bolls. Lint of good length and abundance was found more regularly on plants of this type than on other forms of plants. A remarkable combination of desirable characters was obtained.

The essential features of the Acala cotton are the upright habit of growth and the ability to set promptly a good crop of large, well-shaped bolls. The fruiting branches have joints of moderate length, not of the short cluster form. The bolls open well and have the storm-proof character of holding the seed cotton in place for a long period. The fiber is abundant and of even length, attaining 1⅛ to 1 3/16 inches when raised under favorable conditions. The staple has a firm body and a good "drag," and excellent spinning qualities have been reported from the mills.

The behavior of Acala cotton in Oklahoma in 1919 was described in an article by Clarence Roberts (*40*) in the Oklahoma Farmer-Stockman for December 10, 1919. The storm-proof character, good yields, early maturity, high turnout at the gin, and length and strength of staple were the features specially noted. In that season premiums from $15 to $40 per bale were reported.

Reports for the season of 1920, published in the Marketing Bulletin of the Oklahoma State Market Commission (*35*), January, 1921, showed larger yields from Acala cotton than from other varieties, production of the crop in shorter periods, and higher premiums for the fiber. Maturity of the crop in 90 days was reported in two cases, below 100 days in four cases, and in 110 days or less in five other cases. The turnouts varied from 31 to 38 per cent of lint, 15 of the 23 reports being 35 per cent or above. Premiums of from 100 to 800 points are shown in 15 reports, 12 reports showing 300 points or more, or an average premium of 382 points in the cases given.[2]

Comparisons of Acala with many other varieties were reported in 1928 in a bulletin of the Texas Agricultural Experiment Station (*36*). Acala ranked first in yield of lint from 1922 to 1927. Only one variety, Lightning Express, was reported as earlier than Acala in this series of tests.

After the good qualities of the Acala type of cotton had been definitely determined the seed was distributed, and in a few seasons the new variety was widely appreciated. Indeed, its popularity soon became so great as to invite disaster, since the stocks of good seed were entirely insufficient to meet the demand. Large quantities of mixed seed were planted, or mixtures of other varieties sold as Acala. Some of the fields showed small proportions of genuine Acala plants, while in other fields no such plants could be detected. The better stocks of seed rapidly disappeared as a result of mixing at public gins, as at that time there were no communities where separate ginning of different varieties was practiced. A few private breeders or seed firms undertook to develop stocks of Acala cotton, but much of the seed obtainable from such sources was badly mixed.

[2] Though 25 reports are indicated, 1 is missing from the list, and several are not complete. A list of 28 addresses where planting seed of Acala cotton was offered for sale in Oklahoma in 1921 is included.

Selection was attempted by several volunteer breeders, but often the true type of the variety was not recognized. Hybrids or divergent forms lacking some of the characters of the genuine Acala type were substituted. Crossing with other varieties took place extensively, and many hybrid plants could be found in the mixed stocks. It was natural that breeders who had been engaged with the Texas big-boll varieties should select from the mixed Acala stocks the forms of plants that were considered desirable in Mebane and Lone Star or in other Texas varieties.

Thus the variety was mongrelized by some of the local breeders, instead of being improved, and it might have followed the usual course of being discarded in a few years if the breeding work had not been maintained elsewhere. The only opportunities for maintaining the selection of the Acala type under the condition of complete separation from other varieties have been in California, where pure-seed districts have been established for growing this variety exclusively. The subsequent development of Acala production in California has been described in other publications (*3*, *30*).

Supplies of pure Acala seed have been available in California since 1920, and the use of the variety has extended gradually until in the irrigated valleys of California, Arizona, New Mexico, and western Texas most of the cotton raised is Acala. Better stocks of seed are being developed in Texas, Oklahoma, and Arkansas, so that the use of the variety is again increasing, and the favorable results of the earlier years are being repeated. It is plain from the past experience that the extent of utilization of the variety may depend entirely upon suitable stocks of seed being developed and maintained in the different cotton-growing regions.

The danger now is that a wider use and appreciation of the variety may lead again to a general mixing and deterioration of the seed stocks unless a system of selection can be applied on a sufficient scale, so that entire communities in different regions of the Cotton Belt can be supplied with pure seed and establish new centers of continued production. Without such precautions no large volume of good Acala cotton is likely to be produced in the eastern Cotton Belt to an extent that will show the full value of the variety.

Unless selection can be directed to the true type of the variety, there is the same danger as before, that off-type plants may be selected and local stocks of seed developed with divergent characters. Selections may be made from Acala cotton with differences as great as between other varieties. Such departures from the type could only lead back toward the general condition of diversity and mongrelizing of seed stocks, though all might be derived from Acala. Even in California, where the principle of 1-variety production of cotton has been most definitely adopted, the need of holding the selection of seed stocks to a single type of plant is not appreciated fully, nor is the danger realized sufficiently of replacing one type with another before adequate tests have been made to determine whether any advantage will be gained.

SELECTION FOR PRESERVING A TYPE

After a superior form has been found and separated from a miscellaneous stock, selection has another function to perform in order

to maintain the true characters and qualities of the recognized type during the period of use. The development and the preservation of varieties are different functions, though both are accomplished by selection.

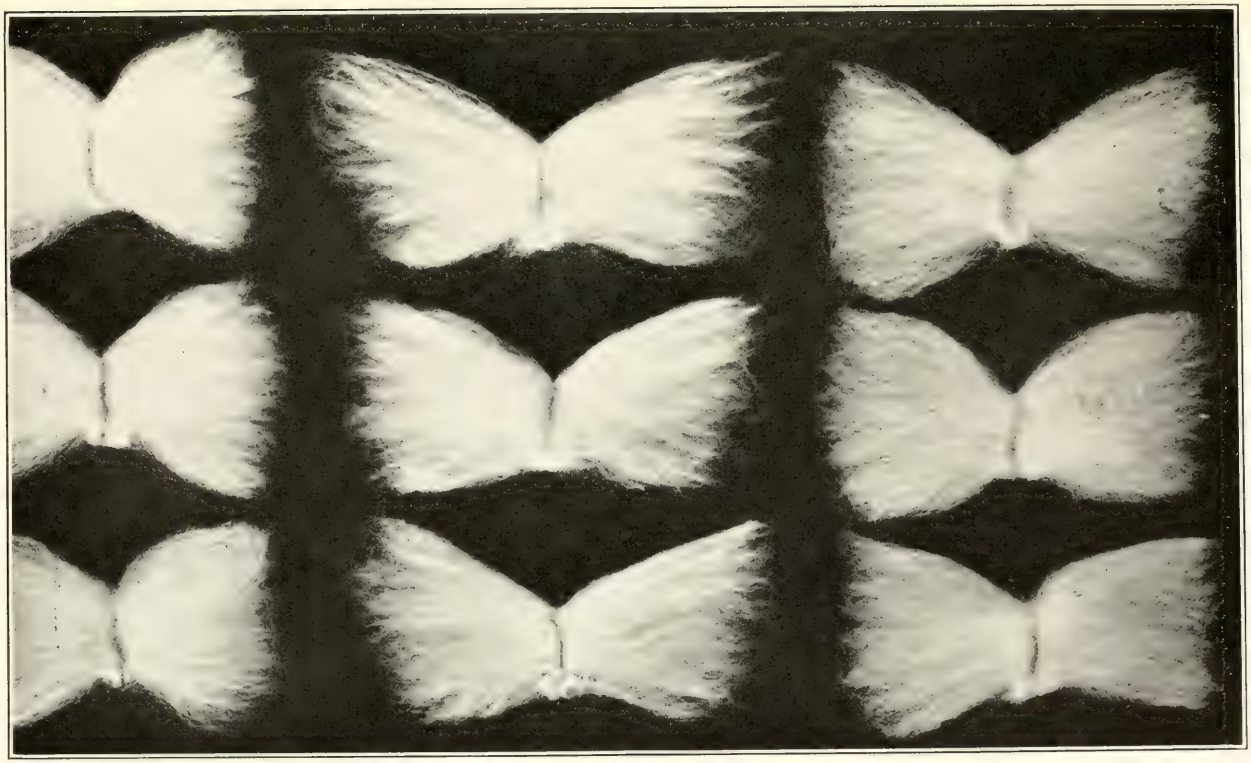
The need of holding to a single type in the selection of a variety of cotton, in order to maintain its good qualities, was recognized in a publication issued in 1910 (*7*). Attention was called to the use of the external characters of the plants to facilitate the recognition and removal of off-type individuals from progeny rows and increase fields. Later experience has tended strongly to confirm the need of such precautions and of bringing the principles and methods of type selection more definitely to the attention of plant breeders and seed growers.

Unless a type is recognized, there is no assurance that the operations of breeding and selection will produce a uniform stock or maintain a condition of uniformity after it is once established. Taking account of the many characters of a type and of the many modifications of such characters that are possible under different conditions, also of the endless departures from the type that may be found as contrasting individual variations, it is plain that experience and careful observation of even a single type of cotton will afford material for extensive study.

The type to be selected necessarily remains indefinite in the sense of its characters being subject to the influences of local conditions. Caution, therefore, is always required in order that the breeder may adjust and accommodate his ideas to the facts before him. Any fixed idea of a particular character that must be expressed in a definite way, as a certain size and shape of bolls, is to be avoided. A score-card standard brought from another place might not result in holding to a type but in slipping away from it.

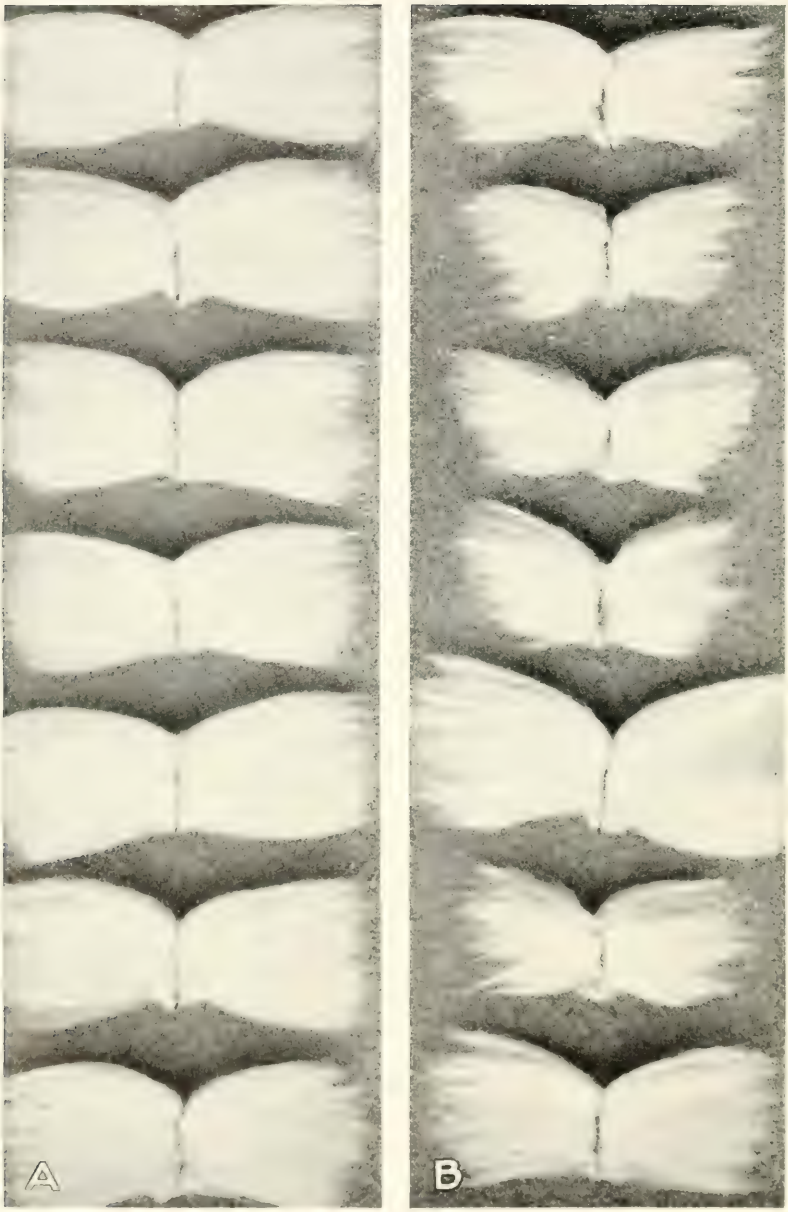
Outstanding departures from the type are easily recognized and discarded, even by the beginner. Many off-type plants are obvious freaks, even to the extent of complete sterility in some cases. (Pl. 24.) Hardly less striking are plants with defective or misshapen bolls, bolls of very small size, as those in Plate 17, or larger bolls of markedly divergent forms, as those in Plate 18, as compared with normal forms, as those in Plates 1 to 3. Variations in habits of branching and in characters of the seeds and lint have been described in a separate publication (*32*), to which reference may be made by those particularly interested in cotton breeding. The inheritance of several of the off-type characters was tested by comparisons of numerous off-type progenies at Sacaton, Ariz., in the season of 1924. Several of these variations showed the cluster or semicluster variations, with short-jointed fruiting branches, while others were rank, unproductive plants, and some were of nearly normal form. (Pls. 25 and 26.) Some of the off-type plants gave notably uniform progenies, while others were remarkably diverse, like the perjugate (second and later) generations of hybrids between widely distinct species.

Though all characters of the plants are subject to variation, differences in the form of the bolls are among the more tangible features and serve best to illustrate the nature of the variations that need to be recognized in selection for maintaining the type. The breeder's



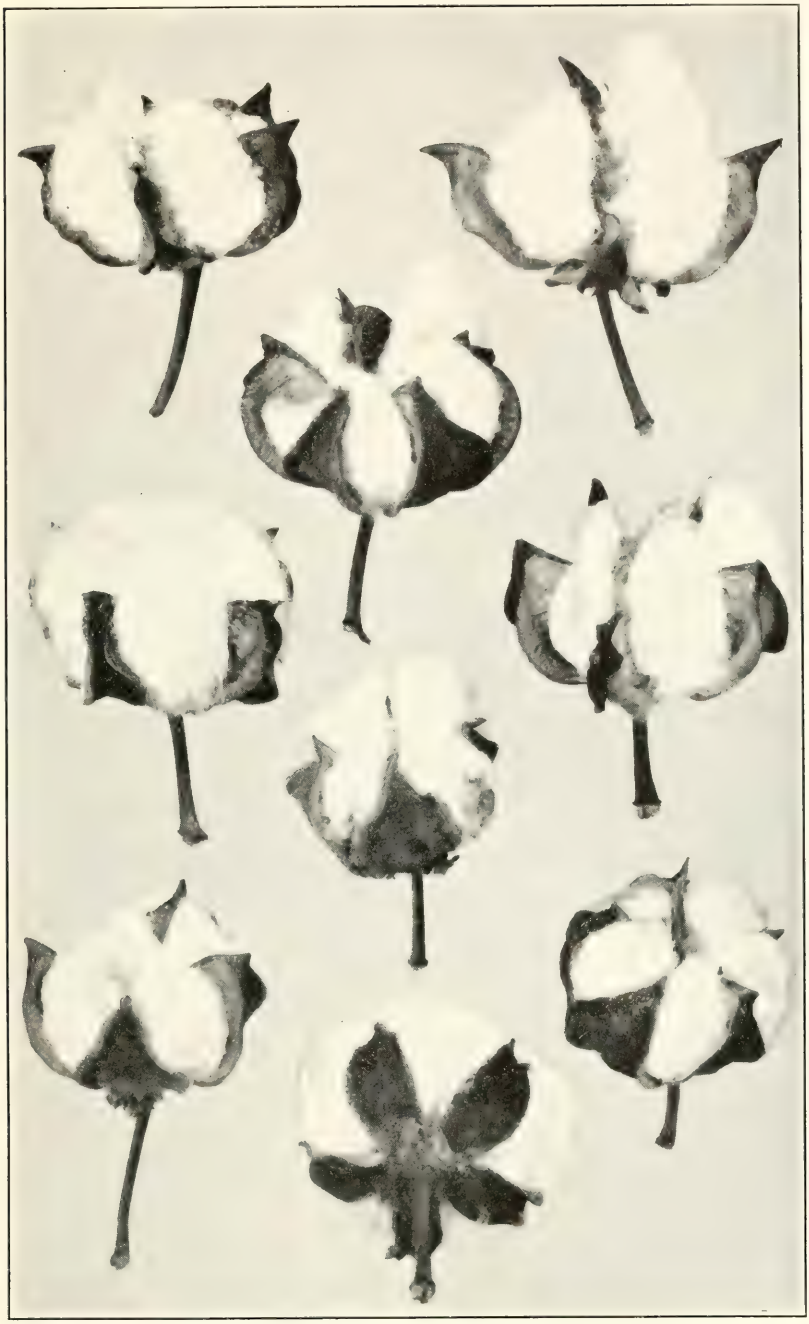
LINT FROM A "BUTTERFLY" COTTON HYBRID AND ITS PARENTS

A hybrid between Triumph or Mebane and Durango cotton, showing uneven "butterfly" lint, shorter at the base of the seed. Mebane cotton at left, Durango at right, the hybrid between. Note even lint of parent varieties, in contrast with hybrid. (Nearly natural size.)



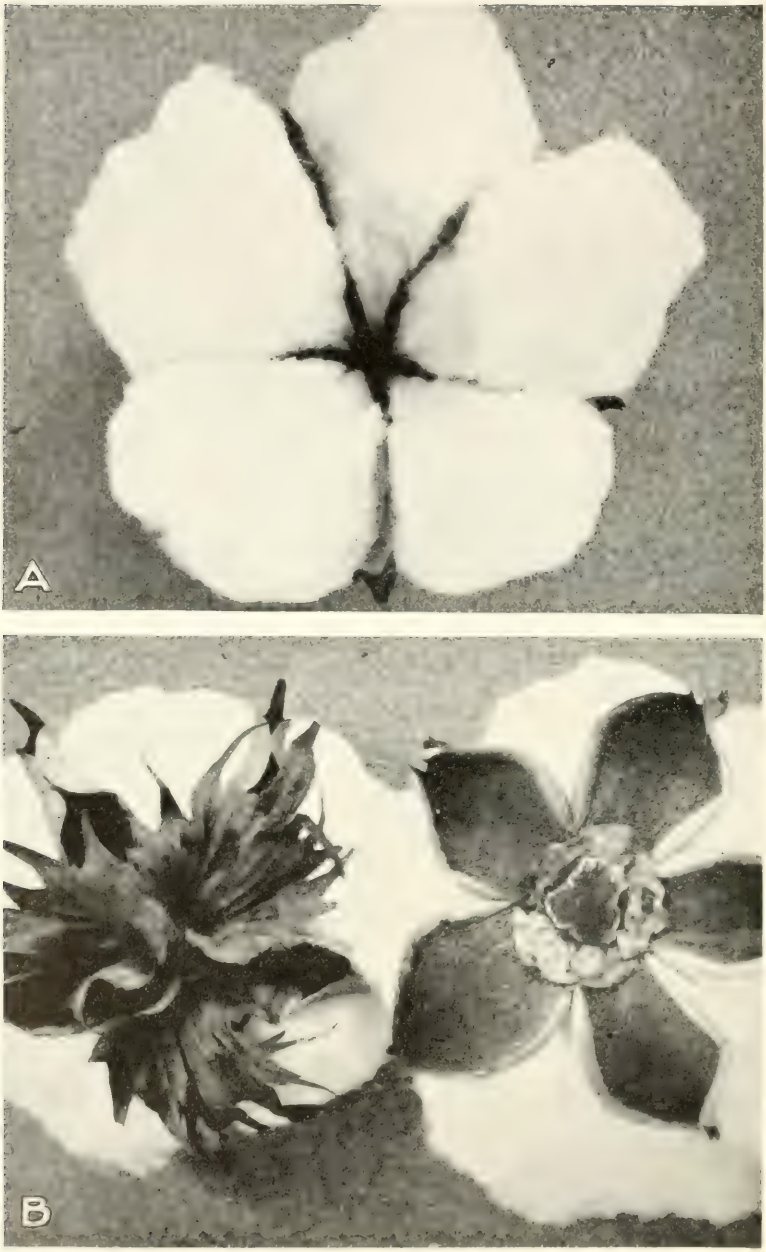
FIBER VARIATIONS OF ACALA COTTON

Combed seeds from a normal Acala progeny (A) and from a rogue progeny (B), the latter notably irregular, with some of the plants reverting to short "butterfly" lint, which does not appear in the normal Acala type. (Nearly natural size.)



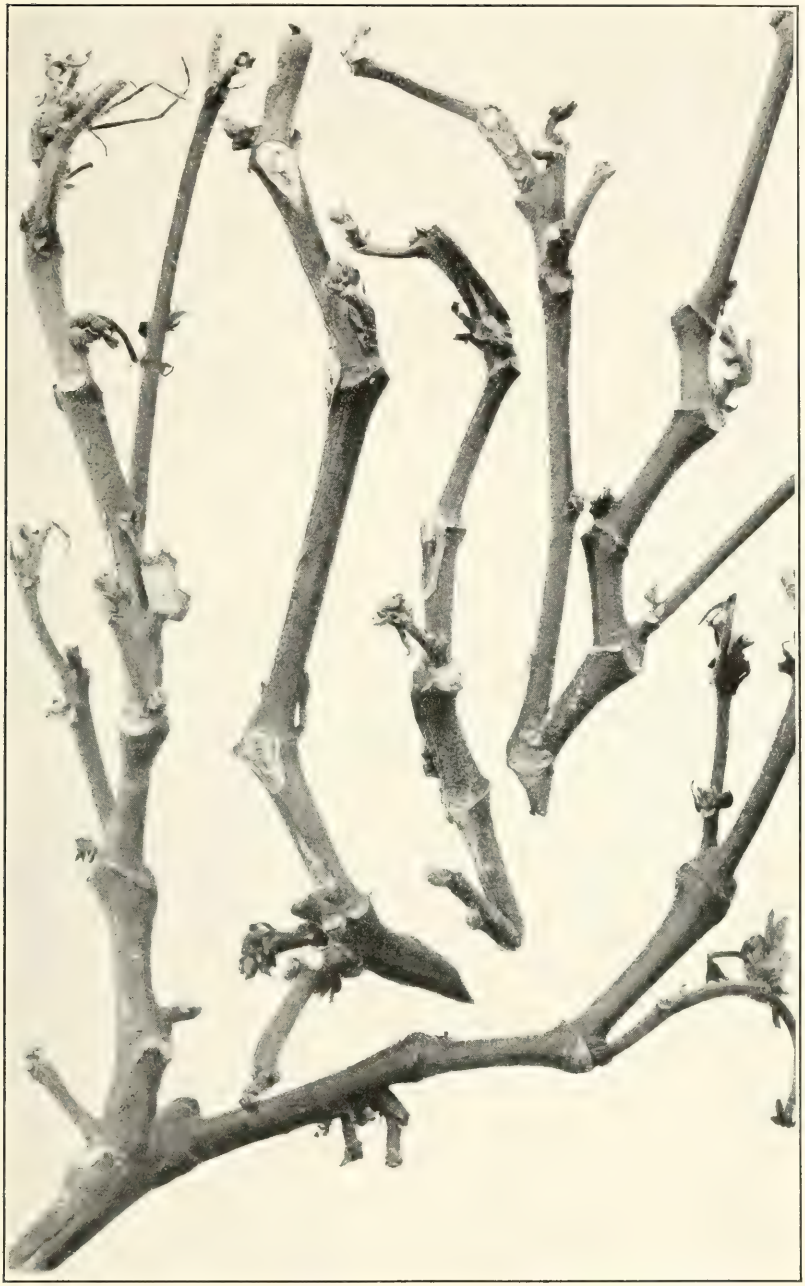
COTTON BOLLS INJURED BY STRESS CONDITIONS

Upland cotton bolls seriously dwarfed by checking of growth under stress conditions. The fiber of such bolls is much shorter and weaker than that of well-developed, normally opened bolls, such as are shown in Plate 23. The three bolls at the top are Acala, the three middle bolls are Lone Star, and the three at the bottom are Mebane. (Nearly natural size.)



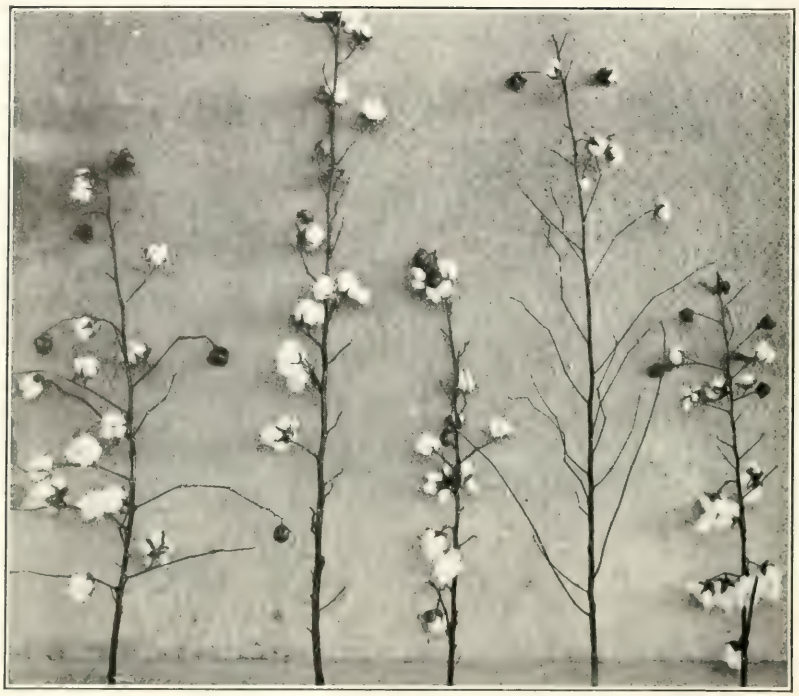
OPEN BOLLS OF ACALA COTTON

Upper (A) and lower (B) surfaces, showing small involucral bracts and compact storm-proof locks, held firmly between the divisions of the boll wall. Compare with the dwarfed, stress-matured bolls in Plate 22. (Natural size.)



A BARREN OFF-TYPE PLANT

An extreme variation of Acala cotton in a field of productive plants at Las Cruces, N. Mex., October, 1926, resulting in complete sterility through abortion of all the flower buds, as shown by the scars of the fruiting branches. (Nearly natural size.)



BRANCH VARIATIONS IN OFF-TYPE PLANTS

Normal plant (at left), three forms of cluster and semicluster plants, and one large sterile plant (second from right).

OFF-TYPE ACALA PROGENIES

Plants representing two off-type progenies, one rank and unproductive, the other of nearly normal form. (Sacaton, Ariz., 1924.)

endeavor must be to establish a correct judgment that will make the proper allowance for local influences or adaptations of boll forms in the true type of the variety and at the same time will not fail to recognize any departures from the type. For each undertaking in selection the breeder must be ready to give himself a few hours of special education, through careful study in the field, in order to have proper ground for confidence in his ability to recognize the type readily and accurately under the local conditions. If the plant forms and boll forms are normal and familiar, selection may proceed without delay, but if it is necessary to take new bearings, this should be done carefully. The need of these precautions and of avoiding fixed ideas of a type will be appreciated by considering the range of boll forms shown in the illustrations of bolls of the Acala type in different places. (Pls. 1 to 4 and 6 to 14.)

Comparison of the boll forms from different localities makes it plain that the local phases of boll forms may cover a range of differences much greater than those that may separate two strains or even two varieties growing in the same place. The Durango boll forms, as shown in Plate 5, are hardly more different from some of the Acala boll forms than some of the latter are from the others. The Acala boll form at James Island, S. C., in 1927 offers as great a contrast to those of Acala from several other places as to bolls of other varieties. Compare Plates 9 and 10 with Plates 1 to 4 and 6 to 8.

Even in the same locality it is necessary to make proper allowances in the recognition of a type. Not only do the plants grow to different sizes and show different habits of branching, which are dependent upon the seasons, but also the forms of the bolls may be notably different. Thus the bolls of Acala cotton produced in 1927 on James Island, near Charleston, S. C., were notably smaller and of a narrower and more pointed shape than those produced in 1926. Compare Plate 8 with Plates 9 and 10.

In curious contrast to the narrowing of the bolls on James Island in 1927, a marked tendency to shortening and blunting of the bolls was observed at Fayetteville, N. C., in the same season. (Pl. 7.) Also these shortened bolls were in contrast to those produced at Fayetteville in the previous year, which were nearly normal. (Pl. 6.) But when these bolls of 1926 at Fayetteville are compared in turn with bolls of 1926 at James Island, they are seen to be somewhat narrower. Thus the season of 1927 showed unusual forms of bolls in both places, narrower at James Island and broader at Fayetteville, and in both cases it happened that the local tendencies shown in the previous year were reversed. It was noted in 1926 that much of the cotton in the vicinity of Fayetteville showed a buckling of the leaves, due to a slight contraction and yellowing of the margins, which suggested that the plants might be suffering from a mild mosaic disease.

Even in the same place and on the same plants appreciable changes of boll forms may occur with the advance of the season. The late-season bolls often are larger and generally are distinctly broader and more abruptly narrowed at the base than the bolls of the same plants formed earlier in the season. A rather striking example of seasonal

variation in boll form was noted at the New Mexico College of Agriculture in 1926. The late-season top-growth bolls were notably shorter and broader than bolls that had developed earlier in the season. (Pls. 3 and 4.) The leaf characters and habits of growth may also show changes late in the season, especially on plants that start into new growth after a period of dormancy resulting from stress conditions.

Reference is made elsewhere to fluctuations in the shapes of individual bolls of the same plant, which are a further indication of the need of familiarity with the plants and of cautious judgment in selection, disregarding the differences that are not significant, but not overlooking any tangible indications of plants that are not representative of the type. When the facts are considered it is plain that mistakes may occur readily under any casual procedure that bases its decisions on inspections of individual plants without the precaution of establishing the local type. Though the external boll characters are of little importance in themselves, they are important to the breeder as the readiest means of recognizing departures from the type which are not signified in the form or foliage of the plant. Many departures from the type can be detected in this way without waiting or taking the time that is necessary to examine the lint characters.

A simple and practical test of ability to recognize the true type of a variety can be made by any breeder for himself, or by others who may witness his work, in the correctness of judgment of the plant in relation to the lint characters. A beginner in selection should do his first practical work when green bolls are still available, but after some of the bolls have opened, so that the relations of the plant characters to the boll and lint characters can be compared, tested, and verified repeatedly to any extent that is necessary to establish a full acquaintance with the type. A regular agreement in lint characters will be found if the true type is being recognized, while poor and irregular lint, which occurs in many off-type plants, will show that the course of selection has departed from the true type.

A relatively slight variation in lint characters may be found among the plants that adhere to a type, but plants of the good type are not found with notably poor or short lint unless cultural conditions are very unfavorable. Serious departures in lint characters seldom or never occur without departures in plant characters, though some of these are more striking than others. The assumptions of some writers that plants may be uniform in other respects but diversified in their lint characters, or may be uniform in lint while diverse in other features, apparently do not accord with the facts.

The biological principle that facilitates type selection is that variations in different characters are symphanic, or generally occur in conjunction, instead of single characters being changed separately. If the variations were not symphanic it would be much more difficult to detect the changes of individual characters, as required in selection and roguing of seed stocks. Considering the off-type characters as reversions may help to explain the general tendency to shorter or less abundant lint among the off-type plants. Such departures from the type might be expected to inherit their lint characters also from more primitive ancestors.

DIFFERENCES AMONG TYPE PROGENIES

Experience has shown that many differences that are not apparent at once, and that may not be recognized even in careful inspection of a breeding block, may still come through to the breeder's consciousness after days or weeks of continuous contacts with the plants. A block of well-selected progenies may appear to be very uniform, with no outstanding or readily appreciable differences between the rows, but slight distinctions become perceptible with sufficient study and are gradually extended by comparisons among the rows.

In every case where familiarity with blocks of progenies has afforded a basis of judgment, the same conclusions have been reached, that slight but consistent differences exist among the progeny rows. Adjacent rows have not been found that were exactly alike, nor could rows that were not adjacent be matched exactly, as should have been possible if self-fertilization had established a condition of complete uniformity. A large proportion of the seed of upland cotton is self-fertilized. Some of the breeding stocks have had the same parentage for many generations and in many cases have been artificially self-pollinated.

More pronounced or definite differences among the rows or among the plants in the rows would be interpreted as results of different combinations of alternative characters, as in Mendelism, but the usual contrasts and distinctive classes of Mendelian hybrids are not indicated. The slight and indefinite nature of the variations suggests an individual origin, as though an incipient tendency of variation had affected each parent plant and had been carried over to the progeny. Progeny-row differences observed among type selections of Acala cotton may be indicated briefly, to show the general nature of the progeny-drift, or genocline, variations, as they may be called.

The habit of the plants in some rows is seen to be slightly more compact, in some more open and spreading, and in some more vigorous or a little taller. The height of the plants is affected not only by the vigor of growth but also by slight variations in the length of the internodes. Differences may be recognized in the number and development of the vegetative branches, especially in the plants with the tendency to taller growth. The fruiting branches vary somewhat in the length of the joints, tending by degrees to the cluster or semicluster conditions which appear frequently in off-type plants. Some rows may be distinguished by having slightly larger or smaller leaves than their neighbors. The involucral bracts in some progenies tend to be larger and more leafy, in others somewhat smaller or more deeply dissected. The bract differences among progenies are superposed on the larger environmental differences in the development of the bracts, as shown in Plates 1, 4, 5, 6, and 8.

Also in the boll characters slight but consistent differences may be detected among the progenies. The oval shape of the bolls is more pronounced in some of the progenies, while others tend to longer and narrower forms of bolls, to shorter and broader forms, or to other slight modifications. The tips of the bolls, though subject to much variation on the same plant, offer slight differences which appear more definite when series are compared. The difference shown in

Plate 2 between bolls from two plants at Indio, Calif., may illustrate this form of variation. The two lower bolls are more definitely tipped than the three upper bolls.

The greatest diameter of the bolls may be near the middle in some progenies, in others nearer the base. The surfaces of the bolls differ slightly in texture and in the abundance and depth of the oil glands. The black glands may show distinctly on a rather smooth surface, or the surface may be somewhat pitted with small depressions around the glands, and the dark color may be less pronounced on account of the glands being set more deeply below the surface. Though the pitting of the surfaces of the bolls is more frequent and more pronounced in some localities than in others, slight but consistent differences may be found in progenies or individual plants of the normal type. Although the distinction may not be clearly seen in the illustrations, the bolls shown in Plate 11 have distinctly pitted surfaces, while those shown in Plates 12, 13, and 14 are slightly pitted.

The abundance, length, and character of the lint show slight but perceptible differences between adjacent progenies. Also, different degrees of the "butterfly" tendency may appear, with the lint fibers shorter at the base of the seed than at the tip. After the lint is removed from the seeds other slight differences may be perceptible in the coating of fuzz that is left on the surface of the seeds. The length, color, abundance, and distribution of the short fuzz fibers are subject to slight but consistent changes as between the progeny rows. The seed of some progenies may appear to germinate more promptly or more regularly than others, or the seedlings may grow more rapidly, but such differences may be determined by planting depths or by the relation of the rows to the plow furrows.

Similar indications of progeny drift have been observed in select stocks of other varieties of cotton, such as Lone Star, Durango, Kekchi, and Meade, as well as in Egyptian and sea-island cotton. Though progeny drift is hardly to be claimed as a new fact, it apparently has not been studied or viewed as an evidence of the nature of heredity.

In view of the uniformity of the rows and of the slight and consistent nature of the progeny-drift differences between the rows, this class of variations apparently should not be interpreted as a residual of diversity from previous crossing, but rather as arising in the parent plants, though in most cases it may be too slight to be detected in a single individual. The differences are usually so slight that they become perceptible only when they are projected into progenies, so that collective impressions can be formed and compared.[3]

SIGNIFICANCE OF PROGENY DRIFT

The progeny drift indicates that the breeder is not dealing with heredity as a system which is constant or capable of being definitely fixed in a uniform set of characters, but rather with a system which is essentially versatile, having an inherent and constitutional propensity to change. Though the changes as shown among the

[3] As a formal name for progeny drift, such a term as "genorhep" may be useful. The Greek verb rhepo means to incline one way or another, also to waver, shift, or show a tendency. The word genorhep might be defined as a very slight progeny variation, a barely perceptible difference between progenies which have been selected to represent the same type of a variety, as observed in upland cotton.

progenies may seem to be restricted to rather slight differences, a condition of complete and absolute uniformity is not attained.

The slight differences that are found among progenies, even in stocks that are carefully selected, may be of interest from another viewpoint. It is possible that the crossing of lines of descent, even inside the slight progeny-drift diversity of a type population, may retain something of vigor and stability in the stock without inducing the greater diversities which are involved in the crossing of different types of plants. A practical uniformity of fiber characters may be obtained even from plants that are appreciably different, and crossing among these slightly different plants does not produce such a diversity of fiber characters as appears when widely distinct forms are hybridized, such as Egyptian and upland, or upland and sea-island cotton. As absolute uniformity of characters may not be expected, it is in order to consider the range of the minor differences that may exist within the practical uniformity of a carefully selected type, as already enumerated.

The formation of composite stocks by bringing together a collection of desirable types and allowing them to cross, in order to build up superior combinations of characters, was suggested by Allard (*1, p. 260–261*) in 1910 in the following paragraphs:

> In fields of carefully bred and selected cotton, on the other hand, intercrossing is probably a beneficial process. As a result of a more or less complete blending of parental characters in the complicated processes of inheritance, a start made with a number of pure, superior, and uniform types followed by intercrossing must tend to bind very closely within the heredity mechanism of the future plants the original parental characteristics. Promiscuous natural crossing is undoubtedly one of the most potent factors producing variability in a cotton field. A vast amount of the so-called inexplicable fortuitous variation is without doubt traceable to this cause. A number of very promising distinct long staple types which have been grown several years in the experimental fields in Georgia surrounded by varieties and hybrids of all sorts have finally become, through natural crossing, almost hopelessly swamped with hybrid types of every conceivable sort.
>
> A plant that appears to be a mutant may have resulted from some new complexity of parentage induced by intercrossing. Why should not endless readjustments of the hereditary forces tend to produce exceptional plants far more surely than by any process of pure mutation? The writer feels that this very phase of natural crossing is a most important basis for further improvement in cotton. What led to the origination of the striking Columbia variety? Was it the result of what we term mutation forces, or was it due to some interchange of the hereditary units? One of the most promising upland long-staple strains the writer has ever seen gives strong evidence of a cross in the past.

That interesting results might be obtained from such an experiment, carefully conducted through a sufficient period of years, may not be denied, though a uniform product would not be expected unless selection to single separate types were subsequently applied. The present proposal is different to the extent that only a single type is included, although the state of theoretical purity is not attained, in that the individual lines of descent are not absolute duplicates.

Allard's suggestion that mass selection be used as a means of building up a superior type would not be inconsistent with a subsequent use of type selection to maintain such a type after it had been developed. On the other hand, the mixture of widely diverse types brings in the element of degeneration from crossing, a fact that Allard recognizes. This danger is avoided by adapting a type al-

ready in existence. It remains to be determined whether the crossing that still may take place among the very slightly different type progenies has any appreciable effect, beneficial or otherwise.

De Vries (*42, p. 109*) has observed that selection has a double meaning, first, "the distinction and isolation of constant races from mixtures," and second, "the choice of the best representatives of a race during all the years of its existence." The recognition and segregation of a desirable type, and its subsequent preservation by selection, would seem to be implied. It is plain from the context that the reference to constant races is not to be taken in the sense of a fixed or uniform condition of heredity.

Selection applied to cotton with the idea of continued improvement may take a different line from that for maintaining the type. The development of a high-producing strain might be attempted without recognizing the need of holding to a particular type of plant in the interest of uniformity and stability of the characters. The apparent effect of selection would be most pronounced under such a system, since a rapid regression would be taking place as a reaction from the crossing of diverse types.

That it may be possible to eliminate some or all of the perceptible progeny-drift differences by continued selection and self-fertilization in separate lines of descent is doubtless to be expected, but an early attainment of complete uniformity is not indicated by experience with self-fertilized strains of Acala and other upland varieties. Acala progenies from self-fertilized strains have not appeared to be more uniform than those produced in the usual progeny blocks. For practical purposes, an effort to establish a condition of absolute uniformity in the type would be justified only under the belief that a condition may be reached in which continued selection would become unnecessary, which apparently is not indicated.

COTTON VARIATIONS UNDERLYING THE APPLICATION OF SELECTION

INDIVIDUAL BOLL FLUCTUATIONS

Progeny comparisons have shown that some of the individual plants display a greater tendency than others to produce the variant forms of bolls, so that slight differences in these respects among the progenies of such plants are indicated in advance. This is not to say that all of the individual boll fluctuations are of significance in heredity, but when a consistency of departure in boll forms is found, so that the aberrant bolls of one progeny or of one plant are different from those of another, a tendency to variation may be indicated, even in the case of plants that give no other suggestion of genetic differences. A single boll of the broad, the narrow, or the rounded forms shown at the middle and the right of Plate 4 might be passed as of no significance in plants with the more normal boll forms shown at the left of that plate, but not an occurrence of several bolls of the same divergent form. The three upper bolls of Plate 4 were from one plant, the two lower bolls from another, and the variant bolls of the two plants were more different than the normal bolls. This peculiarity might be expected to show in the progeny of a plant having several of the variant bolls, though in other respects divergence

from the type might not be detected in advance. Of course, allowance must be made in comparisons of boll forms for differences in the number of locks. Thus, the narrow boll at the middle of Plate 4 had only four locks, while the other bolls had five.

ABNORMAL VARIATIONS OF BOLLS

Caution has also been advised against the selection of cluster plants and of plants that show deformities of the bolls, which often are associated with the cluster habit. A statement regarding these features is as follows (*23, p. 23*):

> The bolls of the cluster variations of Acala commonly are shorter and broader than those of adjacent normal individuals, and often the broader bolls show distinct grooves or folds at the tips, along the sutures between the carpels. These "split-nose" bolls with partly open sutures are to be recognized as a deformity, comparable to the harelip defect in animals. The tendency to open sutures, as well as the cluster tendency, should be carefully avoided in the selection of superior plants to maintain the seed stocks of Acala or of other varieties.
>
> The open sutures render such bolls more accessible to fungi and bacteria, and in some localities serious losses may result from mildew or rotting that begins at the tip of the boll. Such deformities of the bolls are not confined to Acala cotton, but are even more common in Lone Star and other varieties. Plantings of Lone Star and Acala at Manchester, N. C., near Fayetteville, have shown large numbers of bolls with open sutures, and these are often accompanied by rounded protuberances at the base of the bolls, alternating with the carpels.

Other examples of the extra grooves at the apex of the bolls are shown in Plates 18 and 19. This variation is considered morphologically as a partial reversion to a primitive condition of open sutures between the carpels, which in normal bolls are completely obliterated. This interpretation apparently is confirmed by cases of greater abnormality that sometimes occur, as shown in Plate 19. Some of the open sutures extend the entire length of the boll, intermediate between the smaller grooves that mark the fissures where the opening of normal bolls takes place.

The basal protuberances of the bolls also occur frequently in the Texas big-boll cottons, and possibly are to be associated with the intracalicary organs described in an earlier paper on the general anatomy of the cotton plant (*25*).

The intracalicary organs, as was noted in the original description, are small flaps or protuberances standing inside the calyx and placed alternately with the calyx lobes. Another series of rudimentary organs is often to be found inside the boll as supernumerary carpels. Thus there are three kinds of floral abnormalities which may be of the same general nature, that is, they may be considered as rudiments of supernumerary organs. It has been noted in many cases that more of these abnormalities appeared in the late-season bolls than in bolls that had developed on the same plants earlier in the season. But even in the late-season bolls more tendencies to abnormalities were shown on some of the plants than on neighboring individuals, so that in these features also slightly different tendencies of individual variation may be detected.

A slight departure from the type, which may be difficult to detect and of no practical importance in itself, may serve to indicate tendencies of variation toward abnormality, as stated in the discussion of progeny drift. The forms of bolls in a selection of Acala cotton

at Shafter, Calif., as shown in Plate 16, are only slightly broader and more triangular in outline than the normal Acala type, but the differences are consistent. Under widely different conditions, at James Island, S. C., in 1927, the Shafter selection showed a much narrower boll form, as did other strains of Acala, but the distinctive features of more sloping tips and more abruptly narrowed bases were retained, with the greatest width of the boll nearer the base. The forms of bolls at James Island are shown in Plates 9 and 10; they should be compared with Plates 14, 15, and 16, illustrating bolls of the same stock at Shafter. These in turn are to be compared with the examples of normal boll forms shown in Plates 1 to 4.

The departure from the normal Acala type in the Shafter selection appears much more definite when bolls of the form shown in Plate 15 are found to be common, though a few bolls of the more oval normal form continue to appear, as may be seen in the larger series of bolls of this selection in Plate 16. Many of these bolls show the apical grooves and basal tuberosities which were associated with the cluster tendency in the statement quoted above from the publication of 1927. Not only a general cluster tendency is apparent in the plants of the Shafter selection, but pronounced cluster variations occur rather frequently. The association of the cluster habit and aberrant boll forms as indications of abnormal tendencies therefore seems warranted.

UNIFORMITY AN ESSENTIAL IN COTTON BREEDING

The problems of selection may be better understood by taking account of the different forms or factors of diversity that need to be removed or held in check in order to produce heavy yields of good fiber. Though any features of diversity are of interest from the breeding standpoint, the fiber and yield characters are of primary importance and afford a useful background for a more practical consideration of the problems of selection as actually encountered in choosing and maintaining a superior type.

The fiber characters and the yield characters are alike in one respect, in that they are not definitely known till the end of the growing season, so that preliminary selection must be made on the basis of other features. Also both groups include several characters which are essentially distinct, though they are easily confused in a common result. As yet there has been no adequate analysis of either group of characters, but the subject may be opened to further study by a preliminary sketch. Much fiber is classed as irregular without any effort being made to determine the cause or to distinguish the different kinds of irregularity that may be represented in commercial samples. Yield differences also have remained very obscure and inconsistent, for lack of knowledge of the ways in which the behavior of the varieties may be affected in different places or in different seasons.

Differences in plant characters might seem to be of small significance in cotton, since only the seed characters are of direct economic importance, the cotton fiber being an outgrowth from the seed. Yet the seed characters are reflected in many ways in the plant characters, and these relations of plant and seed characters are the keys to the application of selection.

EFFECTS OF MIXING AND CROSSING

As already indicated, the general diversity of fiber in commercial cotton is contributed largely by the fact that the plants in the fields are different from one another and for this essential reason produce different lengths and qualities of fiber. This factor of diversity is due to the neglect of selection, the mixing of seed of different varieties at the public gins, and the crossing of different kinds of plants in the fields. Much of the cotton crop, therefore, is produced from badly mongrelized seed which can yield only irregular fiber, even under favorable conditions of growth.

Without an examination of the fiber, or even in advance of the opening of any of the bolls, the diversity of plant characters in a field of cotton may show very definitely that the stock is mixed or inferior and that a crop of uniform fiber is not to be expected. The diversity of plant characters is a practical index of diversity of fiber characters, and it is only by careful selection and guarding of seed stocks that this general factor of diversity is to be removed.

A mistaken idea is often encountered, that the yields can be increased or the staple improved by mixing seed of different varieties, which is sometimes done deliberately. The value of hybrid varieties in other crop plants is taken to indicate that similar advantages may be obtained in cotton, and the seed is mixed so that crossing can take place. Also mixing is suggested to some farmers by noticing hybrid plants in the fields, which often are larger and more productive than either of the parent varieties, especially where grown under adverse conditions.

The immediate effect of crossing, as shown by the superior hybrids which appear in the first generation of crosses between upland and Egyptian cotton, or between upland and sea-island cotton, is very misleading. In such crosses between the widely different species, only the first generation of the hybrids is productive, with the plants and the fiber uniform. In the second and later generations great diversity appears, with many of the plants abnormal, the fiber very irregular, and many individuals partly or completely sterile.

It might be supposed that good types could be established by selection among the hybrids, but this has not proved feasible, as the breaking-up process continues for many generations. A series of hybrids between upland and sea-island cotton was carried for 12 generations with no indication of finding uniform progenies. Also many such experiments have been made with the upland and Egyptian cottons, but no uniform hybrid stocks have been obtained. Such hybrids are in a different category from crosses of closely related varieties or strains of the same species of cotton. The effect of crossing between related varieties is to induce somewhat greater variation rather than to cause serious abnormality.

The first generation of a cross between different varieties often shows a notably greater resistance to unfavorable conditions and greater productiveness than adjacent rows of plants grown from pure stocks of seed, so that some of the reports of higher yields from gin-run seed than from well-selected stocks may be explained as results of crossing. In districts where many farmers have good stocks of seed it is possible for large numbers of true first-generation

crosses to be formed as a consequence of mixing. With varieties that are similar, like those of the Texas big-boll series, mixtures are more difficult to detect, since the crosses are not distinguished readily from the parent varieties. The advantage to be obtained from such crosses would depend on the nature of the parent stocks. If the parent stocks have been selected for uniformity alone, or without adequate testing of progenies, they may be low in productiveness in comparison with first-generation crosses.

The effects of crossing different varieties of upland cotton have been investigated only to a slight extent, either from the standpoint of determining how far the vigor and fertility are increased in the first generations of such crosses or by following the effects of crossing into the second and later generations, to see whether diversity and degeneracy appeared. Lint from a first-generation hybrid between the Triumph or Mebane cotton and Durango, photographed in 1910, is shown in Plate 20, in comparison with lint from the parent varieties. The lint was somewhat longer than in the Durango parent, but was unlike either of the parent varieties in being "butterfly"; that is, with the fibers shorter at the base of the seed than at the tip. The "butterfly" character in this case may be considered as a reversion or reappearance of an ancestral feature, like the blue hybrid pigeons produced by crossing two white varieties.

In corn culture it is possible to make use of the increased vigor of the first-generation hybrids, since hybrid seed can be produced in practical quantities by the simple operation of planting two varieties in alternate rows and cutting off the tassels of one variety. This method of quantity production of hybrid seed is not applicable to the cotton plant, in the absence of a specialized male inflorescence like the corn tassel. The only possibility thus far indicated of producing cotton fiber of uniform quality from hybrids is by propagation from cuttings, which under some conditions are readily rooted. In districts where the plants live through the winter, several crops may be obtained without replanting. Apart from such expedients, which as yet have not been tested, no prospect can be seen of hybrids being utilized in the production of cotton, because the mixed stocks produce irregular fiber in the second and later generations. Not only must mixing and deterioration of seed stocks be avoided, and careful selection and roguing applied, but other causes of uneven fiber must be recognized and eliminated as far as possible. The danger of mistaking hybrid plants for desirable variations is avoided under the method of type selection.

DIVERSITY IN FIBER CHARACTERS

The analysis of commercial samples has now been carried to the point that machines have been invented for sorting and laying out the fibers according to length, so that the length composition of the samples can be more accurately determined. But such analysis affords little indication of the causes of the differences in the lengths of the fibers. The different elements of irregularity must be distinguished, if the problem of uniformity is to be solved effectively. The facts must be interpreted by tracing the differences back to the seed stocks or to the conditions of production in the field.

Three general factors or forms of diversity that contribute to the differences found in commercial cotton fiber may be recognized in the field. Some of the fiber difference can be traced to differences among the plants, some to differences among the fibers that grow on the same seed, and some to differences in conditions of production. For breeding purposes the three kinds of differences should be especially considered, because different characters of the plants are involved and different methods of selection are required to eliminate or reduce the different forms. The several factors contributing to the different forms of diversity should be recognized and appreciated in order to make proper distinctions in textile quality and value between different lots of cotton. The careful analysis that is now being applied by investigators of the textile characters of cotton fibers will have further meaning when the differences that are established are traced back to the fields and are understood in their natural relation to the production features.

A fourth class of differences are those introduced by carelessness or defective machinery in handling or ginning the cotton. Cotton may be picked carelessly or left too long in the fields. Cotton that is ginned when it is wet often is badly damaged. But such differences should not be confused with those that can be recognized while the plants are growing or before the cotton is picked.

FIBER DIFFERENCES ON THE SAME SEEDS

All of the fiber differences are not removed by having the plants alike and of one kind in the field, because differences are also to be found among the fibers produced on the same plant and even on the same seed. Each fiber grows out as a separate cell from the surface of the seed and may be said to have an individuality of its own. The conditions of growth may affect the length and strength of the fibers and make them irregular, but even under good conditions different kinds of fibers are found together on the same seeds. Usually there are two kinds of fibers that are easily distinguished—the long lint fibers that are taken off in ginning and the short fuzz fibers that remain on the seed. In most of the varieties of upland cotton the fuzz fibers are abundant and form a complete covering of the seed, so that even after ginning the seeds still appear white. Some varieties have less fuzz, and the black seed coat shows through, giving the seeds a grayish color. A few varieties are distinguished by greenish or brownish fuzz.

The specialization of two forms of hairs, the lint fibers and the fuzz fibers, is more definite in some kinds of cotton than in others, and variations sometimes occur with fibers intermediate in character between fuzz and lint. The so-called "Texas wool" cotton with soft greenish lint may be considered as such an intermediate expression of the characters, having the length of normal lint fibers combined with the bluish-green color and soft texture of the fuzz fibers. In many upland varieties the fuzz fibers often show a greenish or brownish color although the lint fibers are pure white. In some of the tropical cottons the lint as well as the fuzz has a brownish color, even a deep rusty brown in some cases, though most of the so-called brown cottons are only slightly tinged with a very light brownish or tan color.

Varieties with white fuzz are preferred because greenish or brownish fuzz may give a tinge to the cotton, especially when excess linters are run into the bales by ginning too close. Varieties with colored fuzz would have a natural protection against overginning, as an excess of colored linters could readily be seen, while the presence of white linters is seldom recognized, even as a cause of neps and waste. The intermediate stages between lint fibers and fuzz fibers are not desirable, as they add to the quantity of substaple which contributes to the waste in spinning or remains on the seed after ginning and passes into the linters. If the fuzz fibers are long enough to be tangled into neps, the cotton is rendered less valuable for spinning purposes. Seeds with too much fuzz or short fibers should be avoided in selection and the normal separation maintained between the fuzz and the lint fibers. In a study of such relations in the Columbia cotton, the longest and most uniform lint was found in connection with uniform short fuzz on the seeds rather than with the seeds that had the longest and most abundant fuzz (*20*).

"BUTTERFLY" COTTON

Inequalities of the lint fibers also are easily seen. With the lint combed straight on the seed, the fibers at the base of the seed, around the point of attachment, often are found to be much shorter than the fibers at the other end of the seed. In some cases the lint at the base of the seed is only half as long as that at the tip, or the basal fibers may be nearly equal to the others. When the inequality of the fibers is apparent the cotton is said to be "butterfly," since the combed samples with the longer fibers at the top suggest the form of a butterfly. The long fibers may be lacking only at the base of the seed or may be restricted to a small area at the top. Examples of unequal butterfly fibers are given in Plates 20 and 21. The first instance is that of a hybrid between the Mebane and Durango varieties, while the second shows reversions to butterfly fiber in a progeny from an off-type Acala plant.

From the form of the combed samples it is plain that butterfly cotton is undesirable on account of the irregular staple length, and variations showing this tendency are always to be rejected. This precaution is continually needed, as the tendency to butterfly variations is very general, though much more pronounced in some varieties and lines of descent than in others. Most of the eastern small-boll varieties of upland cotton show strong butterfly tendencies. A historical example of butterfly cotton was the variety called Floradora, which, on account of this defect, gained an undesirable prominence at the beginning of the present century. The Floradora was recommended as an earlier and more productive variety of upland long-staple cotton and at first was well received, but when the stage of commercial production was reached the reaction among the manufacturers was very unfavorable, as the fiber was found to be very irregular. The reason was not known to the buyers, though obvious enough in the field, as Floradora showed the butterfly character to an extreme degree. The variation in length of fiber on parts of the same seed sometimes was nearly an inch. The fibers at the top of the seed attained nearly an inch and a half in length, while those at the base of the seed sometimes were only half an inch long. That

such a cotton was selected and placed in cultivation is a striking example of disregard of an essential character.

ESTIMATION OF SUBSTAPLE

In addition to the shorter fibers at the base of the seed, as seen especially in butterfly cotton, short lint fibers are always to be found among the long fibers on other parts of the seed in all kinds of cotton. Although such fiber inequalities are universal, in the sense that they occur in all varieties, varying proportions of the short substaple fibers are to be expected, not only as between different varieties, but also in the same variety under different conditions of growth. Even under the most favorable conditions the fibers are not of the same length, even within an eighth or a quarter of an inch. Many fibers much below the commercial staple length of the cotton are always to be found.

That cottons of all varieties have substaple or under fiber can readily be seen by pulling out the long fibers from combed samples and leaving the short fibers attached to the seed. An approximate separation of fibers of different lengths can be made in this way, which can be used for discrimination of varieties or strains of cotton as one of the precautions in selection, or for showing the effects of adverse conditions. The operation of pulling out the longer fibers should be performed somewhat gradually, to avoid loosening the short fibers and also to make a more careful separation into the different lengths of staple.

FIBER AFFECTED BY STRESS CONDITIONS

Where stress conditions are severe and the growth of the plants is checked suddenly, as often occurs in the irrigated districts of the Southwest, the size of the bolls and the development of the seeds and fiber in the bolls are also affected. One of the first effects of severe stress conditions is that all of the floral buds and young bolls may be shed. Other bolls are checked in their growth and fail to develop the normal number or weight of seeds. Abortion of seeds may occur at any stage of growth, from the small ovules that form the motes to seeds that reach nearly the full size but have shriveled kernels and weakened or "perished" lint. Even on the seeds that do not abort, the lint fibers do not grow to full length, and the walls of the fibers remain thin and weak. The shortening of fiber by stress conditions often is readily perceptible, and bolls of the same plant frequently may show such differences, which sometimes are taken to indicate that the seed has been mixed. An example of shortening of fiber by stress conditions may be found in the department Yearbook of Agriculture, 1928 (*21, p. 239*).

With the varying degrees of stress and of impaired growth of the fibers in bolls of different sizes, every stage of irregularity of fiber and of variation in the proportions of substaple may be expected in commercial samples from the irrigated districts. The damage to the fiber from stress conditions is readily perceptible in the fields, not only by examining the fiber from the injured bolls but even by noting the general development of the bolls and the behavior of the plants. The small, stunted, "pinched" bolls fail to

open properly and are found not to contain normal, well-developed fiber.

High turnouts at the gin may be obtained from fields that have suffered from stress conditions, but should not be taken as evidence that the crop is good, that the fiber is of normal quality, or that the seed is of special value. A very high turnout often results from the seed being light, since in periods of drought the kernel may be aborted even after the fiber has developed.

Later pickings may be inferior to earlier pickings of the same fields. Stress conditions may act more severely on plants that have set a full crop than on those that are developing only a few bolls, so that the fiber of the low-yielding plants may be appreciably better. Picking may be delayed for long periods, especially in the irrigated districts, and the exposure of the cotton in the open bolls may affect the quality of the fiber.

In order to have comparative tests of the strength or other spinning qualities of fiber of different varieties or strains of cotton it is necessary that the test material be grown under the same conditions, preferably in alternating blocks as required for definite yield comparisons. Such material was obtained from a series of experimental plantings of several well-known varieties in Texas in the seasons of 1923, 1924, and 1925. The spinning tests by the Bureau of Agricultural Economics were concluded in 1928 and showed a notable advantage for the Acala variety in the breaking strength of the yarn. The other varieties, in the order of breaking strength of the yarn, were Kekchi, Lone Star, Rowden, and Kasch.

Studies of the occurrence of abortive seeds, or motes, in upland cotton have been reported by Rea (*37*, *38*, *39*). Many upland varieties, including Acala, were examined, and motes were found in all, the proportion varying with the varieties and with the seasonal conditions and increasing in dry seasons. Abortive ovules are found more frequently at the base of the lock, and in that position may be considered as normal for some varieties, in view of their general occurrence. Another reason for considering the basal motes separately is that they do not break the locks and render clean picking more difficult, as results from the occurrence of motes in intermediate positions. Where the abortion of seeds is induced by stress conditions, larger proportions of the seeds may be expected to abort in prolific varieties like Acala than in those that set fewer bolls.

VISIBLE AND INVISIBLE CHARACTERS

The need for maintaining the adaptive characters of varieties adds new elements of complexity to the breeding problems, since some of the most important characters are not of a nature to be directly visible or are perceptible only under certain conditions. The visible changes can be recognized at once as departures from the type and are readily removed; but other changes may occur which, although not visible at the time or while the same conditions continue, may become apparent in later generations, after the stock is placed under other conditions.

The visible changes do not cause serious difficulties in the breeding of cotton when the method of type selection is applied. The plants that adhere to the type in their external, visible characters also are

found to have the seed and lint characters of the type. This is a matter of observation, which any breeder or student of genetics should be able to verify for himself by becoming familiar with the plants. A close association exists between the external characters of the plants and the seed and lint characters, not in the sense that particular characters of the plants have been found to be linked with particular characters of the seed, but in the more general sense that departures from the type in plant characters generally are accompanied by differences in lint and seed characters, so that retention of the plant type is a practical protection of the uniformity of the lint.

It is possible that particular departures from the type in plant characters may be correlated with particular departures in lint characters or in adaptations to conditions, but this has not been determined.

Though a single difference may distinguish an off-type plant, so that it may be rogued out at once, definite variation in a single character seldom if ever occurs. Such cases have been unsuccessfully sought for many years. If one feature of a plant appears definitely different from the type, other off-type features usually are not difficult to find. The new complex of characters often comes true from seed, and may be maintained through many generations of offspring without returning to the characters of the normal type. A narrow-leaf variation of the Acala cotton has been selected carefully for numerous generations, but has not shown the characters of boll or lint of the normal Acala type. It is known that many of these complex variations behave as unit characters when hybrids are made.

Some of the differences between the Lone Star and the Triumph or Mebane varieties will serve as illustrations of invisible characters. The external, visible differences between these varieties are relatively slight and much less important than the internal, physiological differences. The bolls of Lone Star are slightly larger, the fiber usually about one-sixteenth of an inch longer, and the seed also slightly larger, but differences in these characters may be so small as to escape detection, even by breeding experts. The most important difference, and one that might be termed an invisible character difference, is that the Lone Star is somewhat more vigorous and productive, often continuing to set more fruit after growth and fruiting have stopped in the Mebane. Checking of growth in the Mebane cotton may open the bolls in advance of the Lone Star, though the first picking from Lone Star may be larger; also the later pickings of Lone Star are often larger, on account of continued growth of the plants in the latter part of the season.

Lodging of the stalks is another difference between these varieties that in many plantings may not be perceptible, but it sometimes appears very important. Lodging occurs only where the plants grow large and are heavily loaded with fruit. All varieties may lodge where the growth is too rank for the stalks to support the weight of the plant, but marked differences in lodging may appear. The Lone Star may remain erect while the Mebane under the same conditions becomes entirely prostrate. At the next stage of luxuriance, Lone Star also becomes lodged, but the stalks of the Acala are still stronger, so that in several tests the Acala plants have stood

erect where both of the Texas varieties lay flat on the ground. Not only is picking more difficult where the cotton is lodged, but many of the bolls may be rotted by lying on the ground. Half of the crop may be lost in this way.

Differences in susceptibility to adverse conditions, though not perceptible in good fields, become obvious enough where stress conditions occur. In one place the plants may appear closely alike, while in another place notable differences are shown, even to an extent that may seriously affect the production of a crop. It may be reflected in such cases that the constitution of the plants rather than their external characters determines the success of production. Such a distinction may be useful in general discussions of the breeding problems, but should be applied with caution, since the nature of the constitutional differences remains to be determined. Some of them may be connected with definite unit differences in the plants, as observed among the visible characters, while others may arise from varying degrees of stability or coordination of the characters as balancing or reacting upon each other in the course of development.

The hereditary constitutions of the plants may vary in different lines of descent with respect to the control or adjustment of the characters, in addition to other differences. The location of the hereditary elements in the chromatin material of the germ cells and the specialized behavior of this material during reproduction and development are great advances of knowledge, but as yet there is no conception of how the characters are represented in transmission or how they are brought to expression in the development of the individual.

Many of the external characters or differences of varieties apparently have no use, at least in the sense that they have no direct or obvious relation to production. Some of the differences serve as marks of recognition for the types that have been separated as desirable; but this separation by visible characters, though it may be very important from the standpoint of establishing and maintaining the uniformity of seed stocks, does not afford a complete and adequate discrimination of all of the differences that may be found, even in the best and most carefully selected strains.

Physiological mutations may be expected to occur, as well as changes in visible characters, and may result in a decline of vigor or fertility or a greater susceptibility to adverse conditions. Undoubtedly there are internal characters which are not of any direct use or value under some conditions, but may be very important in other places. Care should be taken not to lose any of the useful characters of a variety, though their expression may be limited to particular conditions.

With uniformity in the visible characters maintained by type selection, it becomes possible to conduct more effective selection of the invisible characters, such as earliness and resistance to stress conditions. Such differences will explain why seed of the same stock may produce uniform plants under some conditions, while under other conditions the plants appear more irregular. The differences in the reactions to the conditions could not be detected if other forms of diversity were included in the experiments. The larger differences, as in habits of growth and branching of the plants or in

other structural features, would mask the smaller differences and complicate the questions of determining the strength or weakness of particular lines of descent in the presence of adverse conditions.

EARLINESS CHARACTERS

Earliness may be reckoned among the adaptive or physiological characters that are expressed in the behavior of the plant rather than in its morphological features, though certain of the visible differences are not without significance in relation to earliness. Since the arrival of the boll weevil, earliness has been considered as one of the principal characters in determining the yield, and has received special study. The problem of earliness in cotton is much more complicated than breeders have recognized in the past.

As might have been inferred from the inconsistent behavior of varieties in tests of earliness, several distinct characters are involved, which need to be distinguished before a clear understanding can be reached of the earliness problem as a whole. Each character that contributes to earliness needs to be considered separately, since different earliness characters may be significant in different experiments or at different stages of development of the crop in the same experiment. The relative importance of the characters varies widely with the seasons. Experience has shown that some of the earliest varieties are practically worthless for purposes of production, but claims of special earliness are still used to advertise inferior sorts.

Earliness has been emphasized greatly in recent years, because the usual effect of boll-weevil injury is to shorten the period of setting the crop. With the spread of the weevils through the Cotton Belt late varieties were discarded because they were found to suffer more injury than the early ones. Attention turned generally to the breeding of extra-early varieties, and any character that could be connected with earliness was supposed to be valuable. Many tests were made to determine which varieties produced the first flowers, or the first open bolls, or gave the largest yields at the first picking, in the belief that these characters were very important. Also increased earliness was sought in such characters as the placing of fruiting branches lower down on the main stalk, or the shortening of the joints of the fruiting branches as in the cluster cottons.

In some of these projects the essential feature of earliness was overlooked. The practical object in earliness is not to advance the initial date of fruiting or flowering, but to produce the crop as rapidly as possible after fruiting begins. The earliest varieties are those that can produce the largest crops under short-season conditions, and this is the standard of earliness applied to the Acala cotton. The earliness characters, the methods of breeding for earliness, and the cultural methods of inducing earliness should be considered from the standpoint of total production of the crop without placing an exclusive emphasis on any feature.

EARLINESS IN HABITS OF GROWTH

Some earliness characters are connected with the habits of growth. The production of fruiting branches at the lower nodes of the main stalk, nearer to the seed leaves, enables some varieties to produce

flowers and bolls a few days earlier than others, but this character is of doubtful value for practical purposes. Bolls too near the ground are in greater danger of being soiled or rotted.

Another limitation of earliness is that if bolls are set when the plants are too small less growth may be made and fewer bolls produced. Plants that have set only one or two bolls may stop growing in periods of dry weather, while neighboring individuals or rows that were planted somewhat later and have not begun to fruit will continue to grow and are able to set larger crops when more favorable weather comes. Thus it is possible for varieties to be very early and yet make so little growth that only a small crop is produced. Examples of this behavior were noted especially in the Foster variety, which sometimes showed the earliest flowers and the first open bolls, but yielded only a small crop.

A determinate habit, with a definite cessation of growth of plants after a crop has been set, has been reckoned as a desirable character, tending to earlier maturity of the crop under short-season conditions. In practice it may be difficult to distinguish between a determinate habit and a greater susceptibility to checking by adverse conditions. The difficulty in making practical use of a determinate habit is that if the plants stop growing they may lose time and produce smaller crops than varieties that continue to grow and are able to set fruit as long as conditions are favorable. A variety that stops growing in midseason, though it may open all of its bolls, is not to be valued on that account as an early variety, unless it is found by adequate tests to produce larger or better crops.

Earliness has practical value only in districts that can produce paying crops with reasonable regularity. In localities where the seasons frequently are too short for the bolls to open, so that practical yields of cotton are not produced, the climatic barrier should be recognized instead of placing hopes in obtaining the much-earlier varieties that would be required to avoid the cool weather conditions in the fall. The tests have shown that Acala is a very early variety, with as good a prospect as any other of maturing a good crop under short-season conditions. Many of the tests have been made in California and leave no doubt that Acala is more productive than Mebane or Lone Star, as well as producing a longer staple.

Efforts are made to grow cotton in districts where the seasons are too short, as in the northern part of the San Joaquin Valley in California and in the Sacramento Valley. The periods between frosts may be as long as in some of the recognized cotton-growing districts, and good crops of bolls may develop, but cool weather often comes too early for the bolls to open. Favorable seasons may show encouraging results, but in other years little or none of the cotton can be harvested. Many comparisons of other varieties with Acala have been made to determine their behavior under marginal conditions. Plantings at the United States Plant Introduction Garden at Chico, Calif., have continued since 1917.

The Delfos variety occasionally has outyielded the Acala in the tests conducted in the northern districts, though yields often have been so small that practical cotton growing is not indicated. Earlier opening of the bolls is the advantage to be expected in Delfos, since the bolls are smaller than those of Acala; but the lint percentage or gin turnout is

lower, so that definite advantages in other features would need to be shown. The higher yields of Delfos may be explained by the fact that the seeds are smaller, so that heavier seeding occurs unless the planters are adjusted. The records of the experiments at Chico show that the plants generally were more numerous in the Delfos row sections than in the Acala. Thus a spacing effect is indicated, rather than a larger yield from earlier opening of the bolls in the Delfos variety.

EARLINESS WITH SMALL BOLLS

One variety of upland cotton may be earlier than another because it has smaller bolls that require less time to reach full size or that open more promptly than large bolls. In many comparisons it is found that some of the small-boll varieties of upland cotton begin to open a few days in advance of any of the large-boll varieties. Nevertheless, varieties with small bolls are not preferred, as the expected advantage from greater earliness does not prove to be very important and is counteracted by other less desirable features.

Larger numbers of bolls, of course, must be picked in gathering the same amount of lint from a small-boll variety, and this requires more labor. Fifty or 60 large bolls may yield a pound of seed cotton, while 100 or more small bolls may have to be gathered. Pickers avoid the small-boll cotton and often refuse to gather it at the same price.

Another drawback of the very early small-boll varieties is the short fiber that allows the seed cotton to fall out readily from the open bolls, so that more frequent pickings are required. Otherwise much of the cotton may be lost, especially in stormy weather.

EARLINESS FROM CHECKING OF GROWTH

Apart from the production of early flowers or bolls, some varieties are more susceptible to checking of growth by unfavorable conditions, which often results in earlier opening of the bolls. Plants that have stopped growing may open their bolls with no obvious sign of distress, or the bolls may be dwarfed or "pinched" and opened prematurely. The more persistent fruiting habits of the Acala variety may be said to conflict with that form of earliness which results from checking the growth of the plants by adverse conditions. Varieties that are checked more readily than Acala may begin to open their bolls a few days in advance, but this usually does not mean that larger yields are obtained.

The mistake is frequently made, even among cotton breeders and experiment-station workers, of reporting a variety as late because it continues fruiting after other varieties have ceased, so that green bolls may be found on the plants at the end of the season. Such misunderstandings have occurred in relation to the Lone Star cotton, as well as with the Acala, since either of these varieties may continue growing and fruiting after other varieties have stopped. The Mebane variety often is reckoned as earlier, on account of showing no green bolls at the end of the season, although Acala or Lone Star usually yield more than Mebane, and even the first picking may be larger, as shown in carefully conducted tests. It is only by direct comparisons that such facts can be determined. If any late boll-

are caught by the frost the farmer naturally feels that he has lost a part of his crop, and he may not be aware of advantages already obtained from earlier or more persistent fruiting. The production of late bolls is not inconsistent with earliness, but is a separate character and often of practical advantage.

Early opening of bolls as a result of checking would not be considered as a desirable character, but rather as a weakness to be avoided by selection, especially if it were found that the fiber was not matured properly, which usually is the case with bolls that are opened prematurely in periods of drought. Even apart from injury to the fiber, premature opening of some of the bolls in advance of the main crop is not desirable, as the cotton may be lost by falling to the ground or may be stained or mildewed before the regular picking season arrives.

Cotton that has its growth checked early and matures a small crop of bolls may later put on top growth and set another crop of bolls, but usually too late for them to open before frost. A variety that escapes checking in the summer may open more bolls in the fall than one that began to show open bolls in the summer, as a result of checking. Some varieties stop growing, while others continue under the same conditions. Once the growth is checked, time is lost before it can be started again, so that the earliness and yield relations of varieties often appear to be reversed in different seasons. The varieties have different reactions to the weather conditions, depending partly upon the stages reached in the growth and fruiting of the plants and partly upon the vigor of growth or susceptibility to checking and shedding.

The extra-early varieties, if placed under very favorable conditions where they are not checked in their growth but are able to fruit continuously, may yield well. On the other hand, varieties that make somewhat more growth before fruiting is begun are on a safer rooting for setting good crops of bolls in short periods of favorable conditions, as in weevil-infested regions. Shedding of the early buds or young bolls may even appear as an advantage under severe stress conditions, as enabling a variety to put on a larger crop in a subsequent period of favorable weather than if the early bolls are held. If conditions become definitely unfavorable, as in periods of water shortage or very hot weather in the southwestern valleys, the varieties that have set early bolls are checked more than the others and lose more time before growth is resumed.

EARLINESS INDUCED BY CLOSE SPACING

In the cooler districts, where the growing seasons are shorter, the precaution of closer spacing of the plants in the rows should not be overlooked. No advantage in yield has been shown from leaving the plants more than 6 inches apart. Two plants in a hill 12 inches apart, or a hoe width, is the spacing now generally advised, though wider spacings are still used by many farmers. With moderately open stands, where the plants average 2 to 4 inches apart, cotton that is not thinned often yields more than adjacent rows where wider spacing is given.

Restricting the size of the plants tends to an earlier opening of the bolls. Where close spacings are used under short-season conditions

the advantage may be strikingly shown. In rows where there are no breaks the plants are regularly restricted in size, and all of the bolls may open. At the ends of the rows or where breaks occur plants of larger size may develop, and these may continue their growth too late in the season for the bolls to open before frost.

Cool weather in the fall is a limiting factor of the crop in the more northern districts of California. The plants may stand uninjured, apparently with no change of condition, during several weeks before they are killed by frost. Reference has been made already to experiments at Chico, Calif., where the rows of Delfos cotton had closer stands than the Acala rows and gave higher yields, although in other experiments Acala outyielded Delfos.

Under long-season conditions different spacings of the plants at 6 inches, 1 foot, or even 2 feet may show little difference in the yields; but the yield differences become much more pronounced under short-season conditions and may amount to 50 or even to 100 per cent or more, as demonstrated with Acala cotton at San Antonio, Tex., in 1914. Under the conditions of that experiment the period of setting the crop was restricted to about three weeks, on account of weevil infestation (*9*, *10*, *11*, *13*, *34*).

An effect of close spacing in some cases is to induce an abortion of early flower buds at very small sizes, before they reach the stage of being infested by the boll weevil. This is a notable and frequent effect with the sea-island cotton, but also may occur with upland varieties, especially if checked by dry weather. In such cases it appears that the losses of the first flower buds in early stages of development are more than made good by setting larger numbers of bolls a little later, since the plants make more growth than if the early buds developed, and the breeding of early boll weevils is avoided.

The Acala cotton is somewhat better adapted for close spacing than Mebane or Lone Star, because the Acala plants usually are narrower and more upright. A further advantage of the stronger growth of the main stalk is seen in the rapidity with which new fruiting branches are added, which in turn makes possible a rapid succession of flowers and bolls. The period between the first flowers of successive fruiting branches in upland varieties is two or three days, while the period between successive flowers on the same branches usually is five or six days (*31*, *33*).

EARLINESS WITH NARROW LEAVES

Soon after the Acala stock was introduced from Mexico, a narrow-leafed variation was found and carried for several years in Texas as a separate selection. Later the narrowleaf stock was transferred to southern California. It seemed that a cotton with more open foliage might be of value from the standpoint of earliness or from that of protection against the boll weevil, either by allowing more of the weevil-infested squares to be dried by the sun or by giving readier access to poison.

In several experiments the narrowleaf Acala has matured in advance of any other variety, and in some instances has given the highest yields, especially in places where the seasons are too short for the other cottons to open their bolls. However, in most of the tests the narrowleaf Acala was found less productive, so that a substitu-

tion of this form for the normal broadleaf type could not be advised. Without waiting for such tests to be made, the seed no doubt could have been sold extensively, as the prospective advantages of the narrowleaf feature could be used as effective arguments.

RESISTANCE TO ADVERSE CONDITIONS

The Acala cotton, like other varieties, suffers severely when the extreme conditions of heavy soils and high temperatures are encountered in some of the irrigated valleys of the Southwestern States, but the damage is not greater than in other upland varieties, and often is appreciably less, as shown in many side-by-side comparisons between Acala and other varieties. Where comparisons are not made and serious damage occurs to the Acala fields it is natural to suppose that the variety must be very susceptible, and this view is often taken by farmers who are disappointed with their crops and do not know that careful comparisons of Acala with other varieties have been made.

Since Acala cotton is more prolific than other kinds, it may have more buds or young bolls to shed when periods of sudden and severe stress are encountered. Allowance must be made in such cases for differences in the fruiting state of the plant when the stress periods occur. The practical indication of better adaptation is that the Acala cotton generally is able to yield more than the other upland varieties and to produce better fiber, even under extreme conditions.

Only in the Egyptian type of cotton, represented by the Pima variety, has a greater resistance to stress conditions been shown than in the Acala. The upland and Egyptian cottons belong to distinct species with many differences of structure and behavior that affect their environmental reactions. A recent investigation disclosed that the leaf temperatures of the Pima cotton are different from those of the upland varieties (*26*), and this fact throws new light on the apparent ability of the Pima cotton to endure high temperatures with less injury. From the readier wilting of the leaves it seemed that the Egyptian cottons were injured more by hot weather than the upland varieties, but now it appears that the wilting of the leaves is a protection against the excessive transpiration required by the upland cottons to keep the leaves in a turgid, fresh condition.

Many of the cotton farmers in the irrigated valleys of the Southwest are new settlers from Texas or Oklahoma or other States farther east and are not familiar with the effects of the extreme conditions upon the crop. The different behavior of the cotton naturally is ascribed to the variety, and many efforts are made to get seed from their home States, though such importations are forbidden by the plant-quarantine regulations, in order to keep out the boll weevil and the pink bollworm.

In the early days of the cotton industry in the Imperial Valley it was found that the Durango cotton was more productive than the Triumph or Mebane cotton, and later that the Acala variety was slightly more resistant to adverse conditions than the Durango. Even under very adverse conditions the Acala outyielded the Mebane and Lone Star in a careful test that was made near Calipatria, Calif., in 1925. Conditions have changed in recent years in this valley, and other crops have been substituted for cotton on most of the

better lands. The effects of extreme conditions on the development of the bolls are shown in Plate 22. The extent of the reduction may be seen by comparison with Plate 23, showing full-size open bolls of Acala.

Extremes of heat and dryness are also encountered in the Coachella Valley, but the plants are not so badly injured because the soils and subsoils are much lighter and more open. Most of the flower buds fall off during the stress periods in the summer months, but the plants continue to grow and are able to set heavy crops in August and September. Large yields are obtained, often more than 2 bales to the acre, though in other ways the full possibilities of the variety are not shown. Even in the best fields the bolls are slightly smaller than those produced from the same seed in districts where the extreme conditions do not occur. Also the fiber in the Coachella Valley does not attain the full length or quality of some of the Acala cotton that other districts can produce from the Coachella seed.

Conditions of production in the irrigated valleys are extremely varied. Not only is a wider range of conditions presented than in the eastern Cotton Belt, but also very abrupt changes of conditions. The soils in many localities are uneven, as could be well imagined, often passing in a few yards, or sometimes within a few feet, from gravel or coarse sand too open to hold water to heavy adobe deposits very impervious to water. Even the loamy or silty lands that appear uniform and fertile may be difficult to irrigate, and the behavior of the plants may be very irregular, even in parts of the same field. Land not properly leveled also grows very irregular cotton; the plants in high places are burned and in low places flooded out.

The proportion of damaged cotton varies, of course, with the locality and the season, but is greater in the districts that have the heavy tight soils. Some of the heavy soils produce excellent cotton if the weather conditions are not extreme, but in several of the irrigated valleys periods of very hot weather are likely to occur, and then the cotton on the heavy land suffers severely, even with the best care that can be given.

The effects of the soil irregularities are more definitely understood in districts where only one variety is grown. In other places it is possible to suppose that the particular variety or seed stock is at fault. The farmer who is not satisfied with his crop decides to change his variety, instead of recognizing his errors and learning to be more careful, either in his methods or in his choice of land.

It is a mistake to plant cotton on land that is not adapted and well prepared for it. The cotton that is grown under adverse conditions is of inferior quality and should not be sold in the same lots with good cotton. The production of large quantities of damaged fiber is becoming a serious handicap in the marketing of the cotton from the irrigated valleys. Many of the American manufacturers have condemned all of the irrigated cotton after receiving shipments of irregular, wasty fiber. The usual commercial classing of the fiber often fails to distinguish the stress-damaged cotton.

The only way that has been suggested for avoiding the marketing difficulties is to keep the cotton from the good and bad fields separate. It is not impossible to do this, as the condition of the cotton in the fields is easily recognized by inspection. Even in the same field, good

and bad areas could be separated if the need of such precautions were recognized. As long as the separation is not made, the farmers must not expect to get more for their good cotton than for the damaged and irregular fiber, which determines the basis price. The more discriminating buyers have separated much of the good cotton and shipped it to Europe, leaving the less desirable remainder to be placed in American markets. A single commercial agency is reported to have handled about 72,000 bales of the southwestern cotton for export and less than 500 bales for the American market. The buyers naturally desire to protect themselves as far as possible from paying the farmers higher prices than necessary, but greater discrimination of quality in the primary markets undoubedly would result in better cotton being grown (*20*).

GROWTH IN COOL WEATHER

One of the special characters of the Acala cotton is an ability to grow in cool weather, which appears also in the Kekchi cotton from Guatemala, but not to the same extent in any of the upland varieties previously known in the United States. In several of the experimental plantings notable differences in early development of plants could be seen, with the Acala cotton outgrowing the other varieties with which it was compared, unless the Kekchi also was included. The differences are not shown in all cases, since periods of cool weather are required for the additional growth to become apparent.

Late in the season the tendency to continue growth in cool weather may again be observed in the Acala cotton, after other varieties have become dormant. A striking example of this difference of behavior was seen at Sacaton, Ariz., in November, 1924, in comparisons of Acala with other varieties. After a slight frost had occurred the Lone Star and Mebane varieties, though not appearing to be badly injured, showed no signs of further activity, while the Acala plants in the adjacent rows continued to function and opened many bolls in the normal manner before another frost occurred. The differences were obvious in the field and were amply confirmed by the harvesting of more cotton from the Acala block.

An additional picking was made November 21, in which the Acala block yielded much more than the others. The totals were 51.5 pounds for the Acala block, 18 pounds for the Lone Star, and 29 pounds for the Mebane. The rows of the Acala block varied from 6.3 to 9 pounds, the Lone Star rows from 2 to 3 pounds, and the Mebane rows from 3 to 5.5 pounds.

The Lone Star plot, as noted under date of November 15, 1924, still had a large number of bolls unopened, while the Acala plot had relatively few bolls that were not open. The Lone Star block, on account of the plants being smaller, had somewhat more exposure, which might be expected to assist in drying the soil and opening the bolls. On the other hand, many of the Lone Star plants leaned over or lodged, while the Acala plants stood erect. In general, it appeared that the late bolls of Acala were held at least a foot higher from the ground than those of Lone Star, and this might make a difference in frost injury. The frost had not been sufficient to freeze the bolls through, though many were blackened on one side. Such

injuries may have been less in the Acala block, judging from the bolls that were not yet opened. A neighboring Durango block also had less cotton open than Acala, while in a block of Hartsville it was noted that the cotton in many of the late-opened bolls had not fluffed, so that the locks remained separate and often fell out. The lanes between the Hartsville rows were well strewn with cotton, which did not occur with the other upland varieties, though some of the Pima cotton also fell out.

Tolerance of cold in the Acala cotton may be connected with the fact that this variety was obtained from a table-land district of southern Mexico at an altitude of about 3,000 feet. The summer climate of the plateau regions in Central America is cool and cloudy, and most of the rain falls in that season.

In the native district of the Kekchi cotton, in eastern Guatemala, the summers are so cloudy and wet that cotton is grown in the winter. The only weather that is dry enough to pick the cotton and avoid rotting the seeds is a short period in the spring months. The Kekchi Indians have the custom of planting their cotton in October, so that it can ripen and be gathered in March or April. It is easy to see that selection under such conditions would favor the development of an ability to grow in cool weather.

In view of the natural qualifications for earliness and tolerance of cool weather, the possibility of utilizing the Kekchi cotton in the northern districts of California has been considered, and comparisons have been made with Acala, including several years of experimental plantings at Chico, but the yields have not equaled those of Acala. The Kekchi cotton at Chico appeared in some seasons to be more susceptible to injury by thrips, as the foliage turned brownish in advance of the other varieties. However, this might indicate a greater maturity of the plants, as the Kekchi cotton, when it behaves normally, is an early-maturing, short-season variety.

The ability to grow in cooler weather may explain why the Kekchi cotton has appeared as the highest yielding variety in several experiments in Texas, both at San Antonio and at Clarksville. Also a fact has been observed in Texas which may explain, at least in part, the ability of the Kekchi cotton to make more growth during the cool weather in the spring. The cotyledons or seed leaves grow larger in the Kekchi cotton than in other upland varieties and no doubt function to a greater extent and for a longer period as true leaves. Large cotyledons have not been observed in the Acala cotton, and it is certain that the ability to make more growth in cool weather is not confined to the seedling stage of the plants in either variety. In several of the experimental plantings, in both Texas and California, the Acala and Kekchi cottons have shown late-season flowers and bolls after the other varieties became dormant from the cold. A curious persistence of the flowers of Acala cotton after a night of severe frost was noted at Peoria, Ariz., November 7, 1924. The frost was severe enough to injure exposed surfaces of bolls, as well as to kill all the leaves, but flowers on the same plants survived. In some cases even the bracts were killed, but the petals were uninjured and opened normally.

That the same variety of cotton should be able to outyield other good and hardy varieties both in the hottest and in the coolest dis-

tricts would not be expected and might be considered improbable. Nevertheless, these seemingly contradictory facts may be capable of simple explanations. The hot-weather and cold-weather adaptations no doubt are separate characters, though working in conjunction. Less checking of growth in hot weather allows more advantage to be obtained from the ability to grow in cool weather. The extent of the advantage would differ greatly with localities and also with the seasons. In a warm spring or an open fall other varieties might be on an equal footing with Acala, but in a cool spring or fall the ability of the plants to continue their growth at lower temperatures might have a definite effect upon the crop. The late bolls are caught by the frost in short seasons, which may be very disappointing to the farmer, but the advantage obtained in other seasons should not be forgotten or confused so as to mistake the production of late bolls for a lack of earliness in the variety.

To insure the retention of this important character of the Acala cotton, it is plain that some of the selection work should be done in places and in seasons that would serve to test and distinguish the plants or the progenies with reference to their ability to grow in cool weather.

STRESS EFFECTS AND GROWTH DISORDERS

From the standpoint of heredity, the differences that are shown among plants under adverse conditions may be considered as of two general kinds. Some of the differences are merely responses or accommodations of the plants to irregular conditions, while other differences appear to be inherent in the plants, although they may become perceptible only under extreme conditions. The second class of differences may be said to show that the limits of adjustment to the adverse conditions are not entirely the same, even among the members of carefully selected groups. Also in some cases it appears that stress effects may induce heritable changes of the characters, though this has not been established conclusively.

That the crazy-top abnormalities are not inherited should not be taken to mean that no impairment may occur in the characters of a select type from exposure to severe stress conditions or to growth disorders. Even a slight disturbance of the normal processes of heredity, perhaps only to be distinguished by means of careful experiments, might cause serious injury if a select breeding stock should thereby lose uniformity.

Differences of susceptibility to adverse conditions commonly are supposed to be due to the state of health or vigor of the individuals most affected. Physiological causes are assumed without admitting genetic differences. Allowance, of course, must be made for many differences that may be merely accidental and without significance in breeding or heredity, but there is no warrant for denying that genetic differences also are involved in the reactions to conditions. The stability and adjustment of the characters may be subject to variation, in addition to differences that usually are admitted to exist among the characters themselves. The effects of subjecting a seed stock or a group of progenies to adverse conditions and of making selection under such conditions need to be studied with greater care.

Stress conditions may be so severe as to render all the plants of a variety abnormal, or great differences may be shown in the nature and extent of abnormality. At the extremes of the series of stress effects are the growth disorders or mosaiclike diseases of cotton which have been described in other papers. The crazy-top disorder of cotton in Arizona shows the greatest range of stress effects, and many of the plants are reduced to complete sterility. Some of the affected plants produce seed, and the disorder has not reappeared in the seedlings, but the tests have not been carried to the point of determining whether the quality of a seed stock may not be affected by crazy top or other extreme conditions (*19*).

The relation of the growth disorders of cotton to mosaic diseases is still undetermined. Some of the disorders do not show the mottling of the leaves which has characterized the typical mosaic diseases, though they are like the mosaic diseases in being manifested only in the new growth of the plants, while the parts that are formed before the onset of the disease remain normal.

Occurrences of the Arizona crazy-top disease in limited spots, often with diseased and normal plants standing indiscriminately in the rows, are favorable to the idea of an insect-borne virus. In Texas the cotton-flea leaf hopper has been suspected of causing the cotton plants to show an abnormal type of growth and become sterile by shedding all their flower buds. Abnormal diversities have been observed in late-season top growth of cotton in Texas, in districts where leaf-hopper injuries have been reported earlier in the season, though no definite relation has been shown (*14*, *17*, *18*, *19*, *27*, *29*).

In view of these extreme effects of local conditions, it is in order to determine the possible relations of such conditions to the quality of seed stocks. Though for some reasons it may be desirable to make selections in districts where exposure to adverse conditions is expected, yet it is conceivable that conditions might be too extreme, so that regular breeding and increase of seed stocks in such districts would not be advantageous. It might be found that seed stocks could be damaged, at least in the sense of being rendered more variable. Such impairments of the quality of seed stocks by adverse conditions have not been demonstrated, but are commonly believed to occur. Few farmers would plant seed from a low yield for fear that the variety had run out. The general tendency has been to restrict all efforts at selection to places where the largest yields were obtained. It now appears that this may be a mistaken policy, but difficulties may also be encountered at the other extreme.

A remarkable feature in some of the growth disorders is that the individual plants as they stand in the rows show great diversity in many features of their abnormal growth, not only in habits of branching and foliage characters but also in the ability of the affected individuals to produce flowers and bolls under adverse conditions. Although the apparent intensity of the disease is seen to depend very greatly upon the conditions of growth, yet the nature of the individual diversities apparently has no relation to the intensity of the disease as affected by the conditions. The growth of the crazy-top plants becomes more normal as the conditions become less ex-

treme, but the individual diversities continue to appear wherever the disease can be recognized.

The range of diversity in the growth disorders undoubtedly is abnormal, as well as the other disease symptoms, but similar reactions of less extent may be expected in the expression of characters among members of normal strains under severe stress conditions. Every possibility that adverse conditions can affect the quality of the seed is worthy of investigation, in view of the popular belief in the superior quality of seed that is grown under favorable conditions. Also it remains to be determined whether the more exaggerated abnormalities and diversities that appear in mosaic or crazy-top affections are not intensifications of differences that may exist among normal plants, and hence of a nature to render some plants more susceptible to changes of characters when grown under stress conditions.

FIELD CONDITIONS AND PRECAUTIONS IN SELECTION

CHOICE OF CONDITIONS FOR SELECTION

Conditions that bring forth the greatest expression of differences in a seed stock afford the best opportunity for selection. Cotton plants appear more uniform and the individual differences among the plants are harder to detect at the extremes of growth conditions. With the same stock of cotton planted in different regions, the diversities that can be seen among the plants are much more apparent in some places than in others. The most striking examples of such differences in the extent of diversity have been observed in acclimatization experiments with foreign cottons planted in different districts or in different seasons in the same district. Also similar differences in the extent of diversity have been noted when inspections have been made of the same varieties grown in different localities from the same stocks of seed.

The greatest expression of diversity occurs where the conditions are balanced between good and bad. Soil conditions may be favorable, but periods of hot or dry weather may occur, sufficient to check the growth of the plants and allow the individual differences in vigor and productiveness to become apparent. Differences among the plants under one set of conditions may be so slight as to be very difficult or impossible to detect, but in other places readily perceptible differences may be found.

Notable contrasts were observed between the behavior of the same selections of Durango cotton grown at the different places in Texas in 1907. Under relatively dry conditions at Del Rio obvious differences were shown between two selections that were compared in detail, while under more humid conditions at Victoria only slight differences could be detected, which in all probability would not have been recognized except for the previous study of the characters at Del Rio. The plants at Victoria not only grew much larger and became more crowded in the rows, so that differences in habits of growth and branching were rendered less apparent, but even with careful checking of points noted at Del Rio, fewer and less definite differences could be found at Victoria. Nevertheless, full expressions of the characters that had been recognized at Del Rio as marking a superior type of Durango cotton were shown later in many other districts of the Cotton Belt.

Field selection is complicated unavoidably by the fact that under irregular conditions many of the differences of the plants in size, vigor, or productiveness are merely accidental. At the same time real differences may exist, though these are difficult to determine. Many selections may be made of plants whose progenies do not appear to have any special value, but if some of the progenies have the desired characters of greater resistance or adaptation to the conditions, and such progenies are retained in the stock, the purpose of the selection is accomplished.

The difficulties of obtaining definite evidence of the value of particular progenies should not be taken as proof that differences do not exist or that the precautions of continued selection are not required. Progenies from poor or mediocre plants, if grown under very favorable conditions, may appear to be as good as progenies from the best plants, but such comparisons, even if made carefully in one place, are not conclusive evidence that differences do not exist that may be shown when the same stocks are compared under other conditions. As the effects of such reactions upon the growth of the plants are cumulative through the season, only slight differences of vigor or fertility are needed to produce notable results in stature or yield when the conditions are such that the differential reactions can occur.

More careful choice of conditions for applying selection becomes feasible in districts where all of the cotton is of the same variety and of the same stock of seed, as in some of the irrigated valleys of the Southwest, where the Acala variety is grown exclusively. In such districts observations and comparisons of the differences of growth, behavior, and diversities of the plants in different fields can be made which are beyond the range of study as long as such differences of behavior are obscured and confused by the planting of many different varieties and mixed stocks, as in the eastern Cotton Belt. The choice of unfavorable or moderate conditions of growth, as affording the best opportunities of selection, has not been customary, but more attention needs to be given to the study of such relations of conditions to the expression of desirable or undesirable characters.

CONDITIONS FOR ROGUING

Roguing is easier and more effective where individual differences of the plants are more definitely shown. In order to be most effective, roguing needs to be repeated at least three or four times during the season. Some of the aberrant characters are shown by the seedlings, as in the color of the cotyledons or in the lobing of the first true leaves. Other off-type characters of foliage, growth, or branching habits become more prominent before flowering, and roguing at that time has the advantage of preventing the crossing of the normal plants with aberrant individuals.

With plants grown under favorable conditions all that lose their terminal buds should be removed, as these generally do not show normal forms or habits of branching, and render the genuine rogues more difficult to detect. This precaution is not applicable where the young plants are badly injured by the tomosis or leaf-cut disorder, so that most of the plants may lose their terminal buds.

In such cases the early growth may be so irregular that roguing is hardly practicable until the flower and boll stages are reached.

Plants that show off-type characters in the petals, stamens, or bracts can be recognized and removed to the best advantage in the early flowering stage. Another roguing may be done to advantage at the stage when the early bolls have attained their full size, so the aberrant boll forms or failures to set bolls early in the season can be detected. Finally, a late roguing is needed to reject individuals that are off type in lint or seed characters (7).

More effective roguing can be done in progeny blocks and small increase plots than on a more extensive scale. Close roguing of large fields of cotton is scarcely feasible, as the effort of attention required for the best work can be sustained for only short periods. The removal of outstanding rogues can be continued, but when such work is checked later other aberrant plants are found, showing that the previous operation was not complete. Even a partial roguing undoubtedly is worth while with any stocks that are to be used for planting.

PRECAUTIONS WITH SELECT STRAINS

Examples of concealed adaptive characters have appeared in strains of Acala cotton when tested in different places. In comparisons of two stocks under stress conditions at Sacaton, Ariz., the behavior and yields differed notably from other comparisons of the same stocks in California. One stock bore its crop early at Sacaton and afterward produced only a few bolls, late in the season, while another stock continued growing and fruiting for a much longer period. In this test the longer-fruiting stock produced a notably larger crop, with differences of 20 per cent or more in many of the comparisons, but the results at Sacaton were in striking contrast with those obtained in comparisons of the same stocks in other places. At Indio, in southern California, the stock that matured early at Sacaton was more uniform than the other and produced more cotton, as the checking of growth did not take place under the Indio conditions. The greater uniformity of one of the stocks would give an advantage in places where the stress conditions were not sufficiently severe to check the growth and fruiting of the plants. On the other hand, the less uniform stock was more productive at Sacaton, by virtue of more persistent growth and fruiting under the adverse conditions.

The comparison of the two strains at Sacaton was repeated in six borders of seven rows each, with the strains represented by 3-row and 4-row blocks in alternation, or 21 rows of each strain. Sixteen of the rows of the longer-fruiting strain produced from 15 to 20 pounds of seed cotton, while only three rows of the other strain produced as much as 15 pounds. The variation in row yields in the longer-fruiting strain was from 12.5 to 20 pounds, the average being 16.8 pounds, while the yield in rows of the other strain ranged from 9.9 to 19.6 pounds, and averaged 13 pounds. On the basis of row averages by blocks, only one of the blocks of the longer-fruiting strain was outyielded by an adjoining block of the other strain.

It is plain from these facts that such a character as susceptibility to checking may exist in a progeny or strain without being recog-

nized. As long as the stock is kept where the plants are not exposed to sufficient stress to bring about a cessation of growth, the difference is not shown, but definite differences may appear when the stock is transferred elsewhere. Precautions against such impairments of seed stocks obviously will need to be taken, in order to maintain the adaptation of any variety of cotton to a wide range of conditions. In reality, very little cotton is grown under conditions so ideal that no periods of stress are encountered during the crop season.

With cotton, as well as other plants, it has been customary to recognize differences of adaptation between the species and varieties. But now it is seen that pronounced differences of adaptation may also exist between lines of descent or closely related strains of the same stock derived within a few generations from the same individual plant. That carefully selected strains of good varieties of cotton are more susceptible to adverse conditions is a belief that often finds expression among practical breeders. Such differences are being shown in comparison between strains of Lone Star cotton in Texas and also between strains of sea-island cotton which are being tested in South Carolina. Some of the sea-island stocks are much more susceptible to shedding of the young buds and bolls under adverse conditions, showing that the full possibilities of production have not been maintained by the system of individual selection used in the past.

METHODS OF TESTING PROGENIES

The planting of progenies from type individuals in adjacent rows is useful for observing their uniformity and comparing their habits of growth and other plant characters which show their adherence to the type. Differences that would not be detected among plants scattered in a field are easily recognized by means of the progeny comparisons, but the usual progeny plantings afford little evidence regarding productiveness or resistance to adverse conditions. Progeny blocks are subject to row variation, even in places where the most regular and favorable conditions for showing yield differences might be expected.

On account of the great variations of row yields, adequate tests of productiveness are not easily made. The methods formerly used in making such tests were found to be of little value. Row differences that may be only accidental are made to appear significant by being multiplied into acre yields. The only way that has been found for obtaining effective comparisons of varieties, seed stocks, or progenies is to limit each test to only two components. The stocks to be compared are planted in alternate blocks, usually of four rows each, with three or four repetitions. This simplifies the tests and makes the results as definite as possible. Blocks of at least four rows are desirable, as outside and inside rows often yield differently.

At the time of picking, the blocks of rows are divided crosswise into three sections, and each section of each row is picked, weighed, and recorded separately. The data obtained in this way afford numerous direct comparisons between the two stocks included in the test.

Comparisons of the yields of the small sections of rows show the regularity or irregularity of the conditions of production in the field and afford a basis of judgment regarding the value of the tests. If the conditions are not too irregular, and consistent differences are shown between the two varieties, the test is considered significant. An alternate block test of two varieties requires at least three of the 4-row strips of one variety and four of the other, with one or two guard rows added to the outside blocks, making 30 or 32 rows in all. With four blocks of each variety, 34 or 36 rows are required. With the plot cut across at picking time into three sections there are 90 or 102 row sections to be picked and recorded, and usually two pickings are made. The guard rows should be picked and recorded like the others, and they often afford data of interest in interpreting the experiments. A diagram of a 4-block test of two varieties or progenies may be found in a recent publication (*22*).

The data obtained from such tests can be combined in several ways. Totals or averages may be very misleading and often have less significance than comparisons that can be made in other ways. The outside rows of the block sections may be compared, or the inside rows, or the four rows of each block section can be treated as a unit. The nine 4-row block sections of one variety can be compared with the sections of the other variety on either side, giving a total of 18 comparisons of side-by-side block sections. Notwithstanding such precautions, it usually is not feasible to determine differences of less than 10 per cent, on account of the wide variations of yields, even among the row sections of the same variety.

The need for such precautions is appreciated when account is taken of notable differences that occur in the yields of individual rows, even in the same stock of cotton. Acala progenies and increase stocks have been grown for several seasons in the same field at Indio, Calif., by H. G. McKeever, and the row yields have been recorded separately. In the season of 1927, for example, the progeny rows showed a range in yields from 51 to 76 pounds, while the yields of adjacent rows of increase stock, all planted from the same seed, ranged from 44 to 88 pounds, and even reached 91 pounds in an outside row. Also in 1925 and 1928 the increase rows showed greater ranges in yields than the progeny rows. In 1926 two outstanding progeny rows yielded 93 and 110 pounds, respectively, the next highest progeny row 79 pounds, and the highest increase row 89 pounds. The productive progeny was separated and a regular test made in alternating 4-row blocks, where it yielded no more than the regular seed stock. Usually the increase rows have been somewhat more numerous, and this may explain their wider variations, though not reducing the interest of the data as illustrating the phenomenon of row differences. Also, it was noted that high-yielding and low-yielding rows were not consistently in the same places, but varied with respect to positions in the field in the several seasons.

A reason for greater row variation in cotton than in other crop plants may be found in the fact that growth and fruiting are continued through a longer season. Cotton is a plant of tropical origin and makes only slow growth in the spring, or until the weather and the soil are warm. Soil differences no doubt are responsible directly

for much of the row variation, though not for all. Slight differences in depth of planting may influence germination, or the seedlings may stand in better or worse relation to furrows made by plows or cultivators. Such accidents may affect the growth of the roots or the supply of irrigation water. Rows that have a better start in the spring and occupy more soil are able to maintain the advantage through the season, so that a cumulative effect is obtained. The stands also affect the row yields, but to a variable extent. Rows with close stands may have distinct advantages in some places, while in other places rows with more open stands may be equally productive.

COMPARING TYPE PROGENIES IN GROUPS

Adequate testing of large numbers of progenies by repeated comparisons in several places to determine their reactions to different conditions would hardly be feasible as a breeding method. Much more seed would be needed for making such tests than usually is available from single plants, and the increase of numerous stocks of seed in separate isolated plantings is a difficult undertaking. Less complicated tests probably would prove more serviceable in practice. Groups of progenies from different places could be brought together and compared, or seed stocks developed by type selection in different places could be compared to see if differences of adaptation could be found. Or progenies from different places might be planted in blocks and these alternated with the best available seed stock to see whether any indications of greater value for selections made in the different places could be detected.

The provision of adequate quantities of seed as the basis of practical tests is often overlooked. For a single comparison in alternating 4-row blocks not less than a half bushel of seed (15 to 20 pounds) of each kind should be available. Usually such comparisons need to be made in successive seasons or in several places, if results of practicable value are to be obtained. Such undertakings commonly miscarry for lack of an adequate supply of seed. From 10 to 50 bushels of seed should be reserved from stocks sufficiently promising to warrant thorough testing, in order to have seed available for a prompt increase of any stock as soon as a special value is indicated.

Under the system of type selection here projected these tests of progenies or seed stocks in alternate-block comparisons would be made when definite determinations of the values of different seed stocks were necessary or desirable. The testing of all the progenies would not be attempted, but only of those that were to be separated as the basis of new stocks.

The effects of self-fertilization also might be determined more definitely in the same manner by comparing series of progenies that had been self-fertilized for several generations with others raised from seed of the same lots and grown under the same conditions, but not protected from crossing with other progenies. Such comparisons would need to be made in different places, in order to determine whether differences of adaptation could be detected or variations in the extent of diversity were shown among the progenies or lines of descent. All the experiments that are carried to

the stage of yield comparisons must be on a rather large scale and are rather difficult and costly.

If progenies are carried in sufficient numbers, provisional comparisons of their behavior under different conditions may be made, even with small quantities of seed, and any that give signs of being weak or defective may be rejected. Such comparisons and rejections would be used merely as a precaution, without waiting for the more careful tests that would be necessary to prove that an actual deficiency existed. If progeny parents are selected under favorable conditions, enough seed may be obtained for small plantings in two or three places, or tests in several places could be made with seed that had been increased in a progeny block. Self-fertilized seed of each progeny could be obtained in limited quantities for tests of the inheritance of recessive characters or of reactions under different conditions. The production of larger quantities of self-pollinated seed in screened inclosures apparently is feasible to save the labor of artificial pollination.

Another procedure that may be advisable in some districts is to divide progeny seed for planting in successive seasons, reserving at least half of the supply of seed for the second year. Progenies that give any signs of inferiority in the first season may be thrown out, to the advantage of a progeny block in the next year grown from the reserved seed. Also, by bringing the more promising progenies more closely together in the second season they may be compared to better advantage and with less danger of good progenies being injured by crossing with inferior pollen.

Using a group of progenies instead of a single progeny as the basis of a stock would not mean that a single definitely superior progeny could not be separated and put into use, after its special value had been determined by adequate tests. The same method of selection would be continued after such a substitution had been made, since the same need would exist for maintaining the new stock, and there would be the same danger of departing from the type by selecting unintentionally a progeny or line of descent lacking an essential character. The choice of a single plant with an unrecognized defect may impair the entire stock of seed, if dependence is placed on the increase of a single progeny to furnish the breeding stock.

In the selection of Acala cotton the precaution was taken, in the interest of safety, of saving the two best progenies, those that seemed to have the most uniform expression of the recognized Acala characters. One of these progenies was planted and the other held in reserve.

Progenies that showed any deficiency or appreciable departure from the type were rejected, while the others went with the increase stock raised from the progeny that was considered best in the previous year, to provide for a more rapid increase to the volume required to supply the community. Under this procedure about seven-eighths of the increase stock was derived from a single best plant, with the other progenies contributing only a small proportion. Most of the progenies were from plants of the best row of the preceding year, and nearly all of the stock from one plant of two years before, or in all cases not more than four seasons from a common ancestor.

PROGENY COMPARISONS IN DIFFERENT PLACES

For three seasons, beginning in 1926, a series of about 20 Acala progenies has been planted for comparison in three places—Shafter and Bard, Calif., and State College, N. Mex., near Las Cruces. The same series was included in the main progeny planting at Indio, Calif., where most of the progeny selection work with Acala cotton in recent years has been done by H. G. McKeever. Studies of these progenies have been made, but without finding pronounced differences of adaptation among those included in the series. Slight differences of local reactions were perceptible, to the extent that progenies noted as being most alike in some of the plantings did not show the same similarity in other places, but no such contrasts were found as between the Acala seed stocks that were compared at Sacaton, Ariz., in 1927 and 1928, as already described. This may indicate that such divergencies are not of frequent occurrence. Differences between the progenies are more apparent at Shafter and at State College, especially in the boll characters, on account of a better development of the bolls at these localities than at Indio or at Bard. Higher temperatures prevail at Indio and Bard during the growing season than at the other places.

An example of possible effects of local environments on the quality of seed stocks was observed at Kerrville, Tex., in 1907, of which a brief account was published in 1909 (*6*). Numerous off-type plants were found in a field of Triumph cotton grown from seed obtained from the breeder of the variety, Alexander Mebane, at Lockhart, Tex. As the Mebane seed stock at Lockhart had been inspected the previous year and found to be very uniform, the off-type plants that appeared at Kerrville were especially noted and seed saved for planting the following season. Their characters did not indicate that the off-type plants were a result of crossing or accidental mixture of other varieties. The range of diversity was very wide among the off-type individuals, but several plants were alike in having very small bolls which did not open before frost, so that no seed was obtained. Progenies of the other off-type plants were raised the following season, and in several of these a definite inheritance of the off-type characters was shown. It may be assumed that the environmental conditions at Kerrville permitted certain characters to come into expression which had been suppressed or restricted at Lockhart, except that too many differences appeared for the effect to be considered as a simple effect of environment. Hence there could be little doubt that definite variations had occurred in the planting of Triumph cotton at Kerrville.

Adequate comparisons should be made between progenies and seed stocks selected under stress conditions and those produced under more favorable conditions. Blocks of progenies from stress-condition localities could be compared under favorable conditions with standard seed stocks or with other blocks of progenies selected from superior stocks grown under favorable conditions. Such plantings would serve the double purpose of determining whether any differences in the qualities of different lots of progenies could be detected, and of increasing the stocks of carefully selected seed. Any progenies that proved inferior or offtype should be rejected, and in roguing the progeny blocks account should be taken of the numbers and

characters of the off-type plants in the stocks from the different places, to determine whether any consistent differences can be found in the nature and extent of such variations from the type. To check these results, similar comparisons should be made in the stress-condition localities to see whether the local selections show any differences of behavior or differences from good seed stock produced elsewhere.

Another test of possibilities of local variation might be had by making a series of progeny selections in the same stock in several different places and then comparing these series of progenies in the several places. Such comparisons would show whether special characters or values appeared in particular progenies or whether the series of progenies from some places were better than those from other places. Consistent differences among such groups of progenies would indicate that different characters were involved in the productiveness of the parent plants at the different places.

SUMMARY AND CONCLUSIONS

How selection is to be applied most effectively in maintaining superior varieties is the general breeding problem of the cotton industry. The theories and methods of selection, in order to serve this purpose, require careful revision in the light of new facts. The factors of heredity involved in the preservation of the varieties need to be studied with as much care as the factors that are involved in the development of new varieties. The production of novelties has engaged the attention of plant breeders almost exclusively. A different technic has become necessary, and a closer approach to methods of continued selection employed in animal breeding. The contrast between animal breeders and plant breeders in the theory and practice of selection is taken to indicate that the state of knowledge among plant breeders is relatively backward, especially in the features relating to the preservation of varieties.

The history of Acala cotton affords practical illustrations of numerous breeding problems, showing limitations of the methods that have been relied upon in the past, indicating the reasons for these limitations, and leading to the recognition of a more effective method of preserving the true characters of the variety, as well as of maintaining the purity and uniformity of the stocks of seed.

The new method is called type selection, in order to direct attention to the essential requirement of recognizing a single type of plant as the basis of selection and thus maintaining the uniformity of the stock. To appreciate and apply the new method to the best advantage, it is necessary to analyze and discriminate carefully between type selection and several other methods that have been used in the past, including mass selection, individual selection, and progeny selection.

The two principal theories of selection, as accepted in many scientific treatises and textbooks, prove to be misleading when applied to cotton breeding, since both have tended to obscure the need for continued selection as a means of preserving superior varieties. The theory of continued improvement by selection encourages frequent changes of varieties and contributes to the unfortunate custom of seed dealers of bringing out a succession of untried new sorts which

are advertised and sold for a few years and then discarded. On the other hand, the pure-line theory has led many to suppose that pure stocks would remain uniform without further selection.

Comparisons of large numbers of progenies of different species and varieties of cotton show the general occurrence of off-type plants and also of slight but consistent differences among progeny rows of the same purebred stock. The recognition of these progeny-drift variations affords a better understanding of the need of continued selection, in order to preserve the characters of superior varieties of cotton, and to maintain a uniform expression of the characters through periods of years. The need of selection is seen to be apart from the question whether a further improvement of the variety is possible, and the arguments that have been used in the discussion of this question need not complicate the work of the practical breeder.

A new requirement of selection is recognized in the need for maintaining the adaptation of varieties to a wide range of conditions. Many comparisons have been made of the behavior of the same series of varieties under different conditions and have shown that a wide range of adaptation is practicable. Selection and testing of progenies under different conditions is recognized as a means of preserving the adaptive characters of varieties, which otherwise may be lost even without being recognized. To maintain the selection of a type it is necessary to be aware of as many of the characters as possible, both visible and invisible, so that all of the essential characters of the type may be carefully guarded.

The usual methods of comparing progenies in single-row plantings in breeding blocks do not afford a basis of selection for maintaining the productiveness of a seed stock. The progeny plantings are subject to the usual row variations, which commonly are great enough to mask any differences to be expected between progenies of the same type. With selection confined to a single locality or to favorable conditions of growth, there is danger that characters of adaptation and resistance to unfavorable conditions may be lost. Difference in vigor or fertility may arise like changes in other characters among the lines of descent, even in a carefully guarded seed stock. In order to be assured of maintaining the productiveness and uniformity of superior types of cotton, it is necessary that selection, comparing of progenies, and testing of seed stocks be done in different regions covering the range of conditions of production. Groups of progenies, instead of single progenies, are maintained as the basis of seed stocks, which are continuously reselected from productive individuals.

Choice of conditions for selection is a precaution to be recognized in practical breeding work for maintaining good seed stocks of superior varieties. Conditions most favorable for selection are those that permit the plants to show differences in reaction to adverse conditions as well as ability to produce large crops under favorable conditions. Differences in stability of characters are to be recognized, as well as differences of actual expression of characters, which may vary greatly with the conditions. The effects of stress conditions on different varieties and seed stocks need to be determined as a part of the breeding operation.

Several of the characters of Acala cotton contribute to earliness of the crop, one of the most important being the ability of the plants to make more growth in cool weather and to open bolls normally after other varieties have become dormant. The Acala plants flower abundantly, so that large numbers of young bolls may be set in a short period. Closer spacing of plants in the rows is a means of inducing earlier opening of the bolls by restricting the size of the individual plants.

Study of several factors of earliness show that some of them are less important than breeders have supposed and need to be avoided in selection instead of being considered desirable. How to get the largest crop matured before frost is the practical question of earliness, rather than obtaining a few open bolls at a very early date, or even an early opening of all of the bolls, since the application of these standards of selection may render a variety less productive.

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THE PUBLIC DOMAIN OF NEVADA
and
FACTORS AFFECTING ITS USE

BY

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Bureau of Agricultural Economics

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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CONTENTS

	Page
Introduction	1
The physical limitations	3
Size	3
Surface relief	4
Climate	4
Erosion	6
Plant cover	7
The forage resources	8
Forage-plant associations and their distribution	9
Grazing capacity	16
The water supply and its use	17
The control of the land and its utilization	19
Methods used in this study	22
The range stockmen	24
The farmers	28
The miscellaneous class	29
Important steps in the development of the livestock industry	31
The legal status of the public domain	37
The recorded range claims	40
Summary and conclusions	44
Bibliography	50

INTRODUCTION

From the time when cattle had spread well over the Great Plains, in the early and middle seventies of the last century, the need of land legislation adapted to that great region was felt by an ever-increasing number of people. By 1890, the range-grazing lands were so thoroughly occupied that organized efforts were being made to induce Congress to take some definite action.

At the annual meeting of the National Livestock Association held in 1898 William A. Richards, of Wyoming (*22*),[2] delivered a paper on the need for Federal legislation designed to give proper control of the public domain.[3] Among other things he said: "During the past 10 years at least a score of bills providing for the cession of the lands to the States have been introduced in Congress." Although the members of this meeting could not agree as to the method of bringing it about, they were all in favor of subdivision and individual control of the public grazing lands.

Year after year the American National Livestock Association has passed resolutions which they hoped would bring about such a result.

[1] The author wishes to express his gratitude to all who assisted in bringing together the information in this bulletin. The study was outlined and carried on under the direction of L. C. Gray, principal agricultural economist, division of land economics, Bureau of

State livestock associations of all the Western States and other local organizations of producers of cattle and sheep on range lands have repeatedly passed similar resolutions and recommendations.

Although many different arguments have been advanced as reasons for such action, the principal motive among these stockmen has been the producers' wish to improve their business and to increase output. They were using the range lands more or less, and they recognized that better management of the grazing, possible only under better control, would produce more livestock.

Technical investigators, members of the faculties of the universities and agricultural colleges of the western "public land" States, have analyzed the situation, each in his own State, and have published their conclusions as to conditions, have emphasized the necessity for Federal legislation, and mostly have recommended a particular type of action.[4]

In 1904 a Public Lands Commission, authorized by Congress and appointed by the President, made a study of existing conditions, their report being published as a Senate document (*23*). This report treats the subject exhaustively from many angles and summarizes the available data. A particularly illuminating part of this report is a large-scale map of the range country showing the manner in which both public and private lands were being used at that time. The report recommended legislation which is discussed later. At the meeting of the American National Livestock Association held in Denver in January, 1919, Clay Tallman, then Commissioner of the General Land Office of the United States Department of the Interior, recommended a certain plan of legislation to Congress (*27*). At that same meeting, David Houston, Secretary of Agriculture, recommended practically the same procedure (*14*). In the summer of 1919, at the call of the Arizona Livestock Association, representatives of livestock associations from all the western range States, assembled at Salt Lake City, discussed the subject at length and adopted resolutions recommending practically the same kind of

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Agricultural Economics. Director Cecil Creel, of the Nevada Agricultural Extension Service, and Director S. B. Doten and C. E. Fleming, of the agricultural experiment station at the University of Nevada, gave valuable assistance in determining various details of the plan. Two district agents of the Nevada Extension Service, C. R. Townsend, of Ely, and J. W. Wilson, of Elko, made it possible to ascertain, in the limited time available, the conditions existing on thousands of square miles of their State. The officials at the State capital, George W. Malone, State engineer, and George Watt, State commissioner of lands, and their office forces furnished every facility for an understanding of the water and land laws, the authorized procedure under them, and the consequences of their application. Vernon Metcalf, secretary of the Nevada Land and Livestock Association, explained the actions and wishes of the members of that organization and helped to clarify many uncertainties. John F. Deeds, of the agricultural division of the Geological Survey, Department of the Interior, furnished access to office records and maps showing distribution of forage plants and irrigated land in Nevada. The supervisors of the national forests furnished much information. Alexander McQueen, supervisor of the Humboldt Forest, supplied recorded data and guided the writer through the three divisions of the forest under his direction and discussed and demonstrated conditions and practices. B. A. McAllister, commissioner of the land department of the Southern Pacific Railway Co., gave access to the records of the railroad grant lands in Nevada and explained the methods of the company in handling them. The county assessors in each county and their office forces helped in many ways. Much information was drawn from their records and from their knowledge of conditions in their respective counties. Other county officials added valuable local data. B. O. Weitz and Alfred S. Dalton, former members of the division of land economics, assisted in collecting and assembling the data and in working out the legal status of land and water in Nevada.

[3] Italic numbers in parentheses refer to Bibliography, p. 50.

[4] Care should be taken to distinguish between the expressions "public lands" and "public domain." All lands over which Congress has jurisdiction are "public lands" except as Congress may have made other disposal. Only those lands which are unallotted, unreserved, and unappropriated constitute the "public domain."

[5] See Bibliography at the end of this bulletin.

legislation (*30*). Hardly a Congress for the last 30 years has been without one or more bills proposing legislation for the disposal or control of the public domain. A major difficulty has been the fact that conditions of land utilization in various parts of the public domain are so diverse that it is difficult to draft legislation equally suitable to all parts of it.

Believing that legislation properly applicable to conditions existing in a single State and satisfactory to the people of that State would readily pass Congress without opposition from representatives of other States,[5] it was decided to make a detailed study of all the factors affecting the present and potential uses of the land in some public-land State and to assemble the data in such a manner as to present a definite picture of existing conditions in that State.

Nevada was selected as representing in an extreme degree several of the factors of major importance in the problem. It is unique among all the public-land States in several ways:

There is a greater acreage of public land in Nevada than in any other State.

This acreage of public land constitutes a much greater proportion of the whole land area of Nevada than may be found in any other State.

The whole agricultural organization of Nevada is virtually determined by the only possible use that may be made of this public domain.

Methods of establishing partial control over public grazing lands, by controlling the stock water, that are in use elsewhere are rendered futile in most of Nevada by climatic conditions.

The necessity for legislation regulating the use of these lands has been most keenly felt in Nevada, and there have been many urgent requests for relief.

This study was begun in 1927, and the data presented relate mostly to conditions existing in 1926. Other data obtained later apply to 1929. No material changes have occurred in the major factors discussed, and the maps and tables present broad generalizations as to existing relationships.

THE PHYSICAL LIMITATIONS

SIZE

Nevada is a very large State, being sixth in order of size. Its surface area (70,285,440 acres of land surface and 556,166 acres of water surface) is about equal to twice the area of the New England States plus that of Maryland. Notwithstanding its huge proportions, when measured by agricultural production its rank is near the lowest, and it is lowest in population, as shown by figures from the 1925 [6] census. (Table 1.)

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[5] The Kincaid Act (passed in 1904), which was practically the same as the grazing homestead act (passed December, 1916), was made applicable to only that part of Nebraska which it fitted.

[6] Figures from the 1925 census (*29*) are used as being the most nearly comparable to the land-tenure and other data for 1926 that have been assembled and mapped.

TABLE 1.—*Comparative agricultural data for Nevada and for two States having comparable areas of crop land, 1925*

Item	Unit	Nevada	Delaware	New Hampshire
Land area of State	Acre	70, 285, 440	1, 257, 600	5, 779, 840
Farms, 1925	Number	[1] 3, 883	10, 257	21, 065
Land in farms	Acre	[1] 4, 090, 586	899, 641	2, 262, 064
Crop land	do	533, 614	518, 859	542, 846
Crop land harvested	do	362, 552	404, 209	533, 386
Pasture land in farms	do	[1] 2, 973, 821	101, 633	1, 087, 385
Value of all farm property	Dollars	98, 056, 358	72, 778, 416	107, 097, 243
Value of all crops	do	8, 445, 833	11, 848, 440	10, 195, 895
Value of all products of farms	do	[1] 40, 500, 764	25, 368, 656	36, 040, 638
Value of land and buildings, per acre	do	16. 62	66. 86	38. 30
Population, 1930	Number	91, 058	238, 380	465, 293
Farm population, 1925	do	17, 034	44, 662	77, 450

[1] Includes all farms and stock ranches in Nevada.

SURFACE RELIEF

The State consists of a series of long, narrow basins (bolsons) locally called valleys, separated by many narrow ranges of parallel and apparently naked mountains that run in a nearly north and south direction, with occasional low cross divides between the basins. All surface drainage in each valley runs toward the bottom of the basin, where there usually may be found a playa—the flat bottom of an ancient lake that has dried up.

These valleys are usually several times longer than they are wide and occasionally they have been connected by drainage channels cut through the low divides. The bottoms of these valleys are mostly at rather high elevations above sea level—2,000 feet or more—and the mountains rise from 3,000 to 5,000 feet above them. The high plains in the northeastern part of the State, which divide the glacial Lake Bonneville drainage area in Utah from that of Lake Lahontan in Nevada, are over 6,000 feet above sea level.

The mountain ranges rise to levels of 8,000 to 10,000 feet or more, and the higher peaks within the State exceed 12,000 feet. A good idea of the general relief features and their distribution may be obtained from the relief map. (Fig. 1.)

CLIMATE

These relief features and the geographic position of the State in the continent determine the amount and character of the average annual precipitation and its distribution in time and place, as well as the temperature variations to which the State is subjected. All parts of the State are dry when compared with common standards, and some parts are very dry.

> The average annual precipitation [of the State] is about 9.62 inches, of which more than half falls in the four months from December to March, and over three-fourths in the seven months from November to May. The winter precipitation * * * occurs mostly in the form of snow. * * * The month of least precipitation is July, and the greatest monthly amounts usually fall in January (*2, p. 2*).

A diagrammatic map shows the areas having the same average annual precipitation. (Fig. 2.)

Extreme range characterizes the temperatures of nearly all parts of the State. Summer temperatures are relatively high and winter

temperatures low for the latitudes, except in the southernmost part of the State, where winter temperatures are rather high. Daily vari-

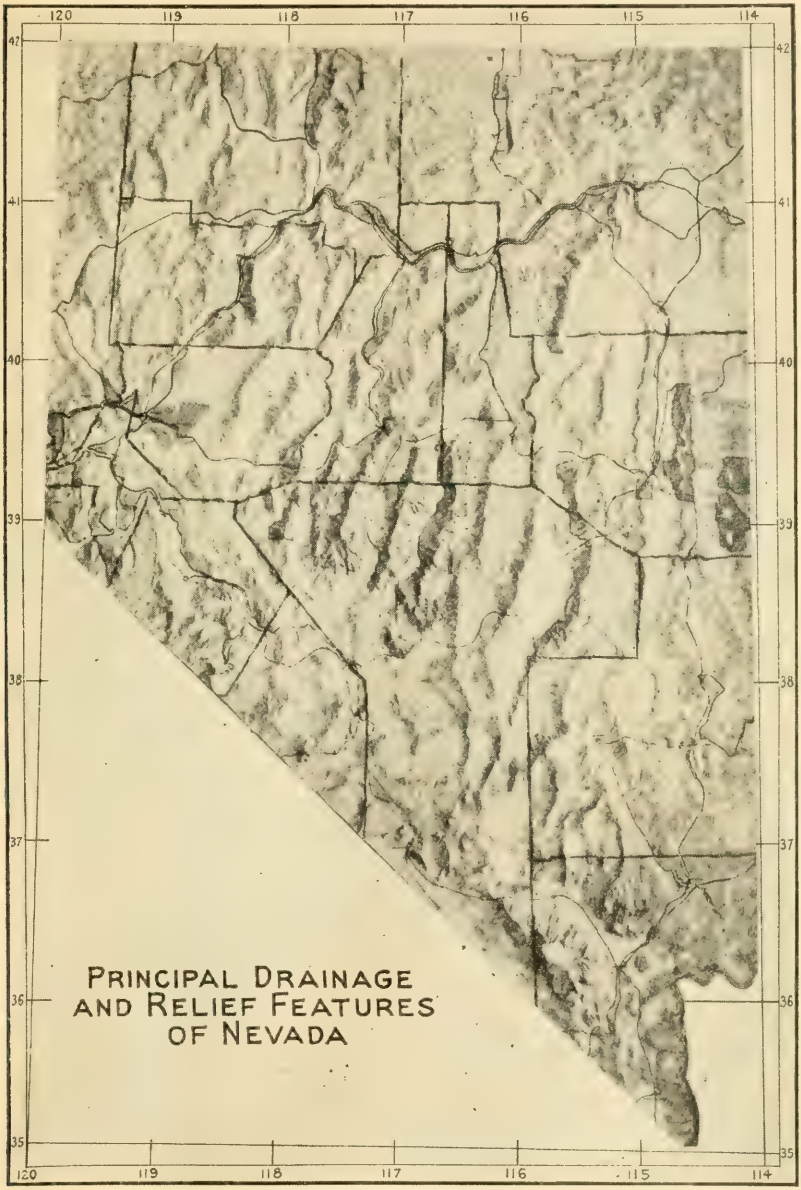

FIGURE 1.—This map was prepared several years ago, from the available data, by William Simpkins. The original, a cast about 5 by 7 feet, is displayed at the State Capitol of Nevada

ations of temperature are large, as is common in most dry regions of moderate-to-high elevations. Strong light and many bright sunshiny days are characteristic of the region.

EROSION

Under natural conditions erosion occurs on all land surfaces where deposition is not taking place. Within certain limits erosion can

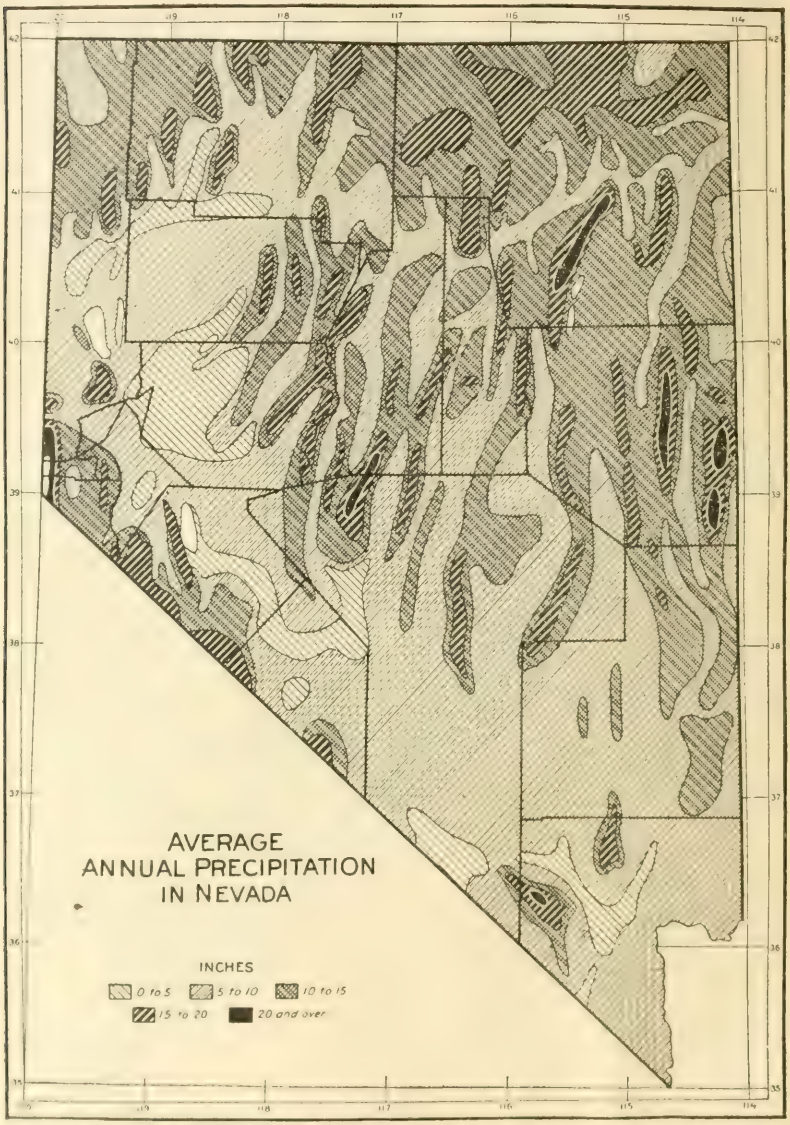

FIGURE 2.—The average annual precipitation at a given station is the average of total recorded readings for a period of 10 years or more. A shorter period is not used because it does not give reliable averages for the station. (After a map published by Aldous and Deeds, as revised by the U. S. Weather Bureau)

be retarded or minimized by human activities, but frequently such activities, although physically possible, are not economically warranted, especially from the standpoint of private enterprises. In Nevada there is and always will be some erosion. There is perhaps

less of it in that State than in any State having similar surface gradients, loose sandy soils, scanty plant cover, and an equivalent total precipitation; for in Nevada most of the precipitation occurs as snow, and the superficial run-off is comparatively small. It is doubtful if any important unprotected area exists in Nevada, for virtually all areas significant for watershed control have already been included in the national forests. If other such areas do exist they should be withdrawn before any steps are taken toward allocating range claims on the public domain.

PLANT COVER

These climatic conditions and the relief features determine the types of plant cover that naturally occupy the land surface of the State. They also determine the place and the amount of crop farming that may be carried on and the kinds of crops that can be grown.

A scanty supply of moisture, coming mostly as snow in the winter with almost none falling during the growing season, has resulted in a natural plant cover consisting of low to medium-sized, long-lived, drought-resistant shrubs on the floors and gently-sloping sides of the valleys. Scattered among these shrubs certain long-lived, drought-resistant bunch grasses grew in some profusion before the coming of the white man's cattle and sheep.

Limited rainfall and the basin structure have resulted in the accumulation of alkaline salts in the soils of the valley floors, particularly along the drainage channels and around the playas. The plants that grow on these alkaline areas must be able to endure alkaline soil conditions, as well as the temperature and moisture limits of the region.

On the mountain ranges, growing conditions for plants are not quite so trying. Soil conditions are better, moisture is somewhat more abundant, and although winter temperatures are low, summer temperatures are more favorable. With such an environment, the plant cover is more abundant and varied. At no place in the State are large areas of heavy forest to be found. Formerly there was a limited growth of yellow pine (*Pinus ponderosa* Dougl.) on spurs of the Sierras that project into Nevada on the western side near Reno, but these trees have mostly been cut. Small forested areas are found in most of the national forests at high levels on the cooler slopes of the mountains.

Woodland areas covered with junipers (*Juniperus* spp.) and piñons (*Pinus monophylla* Torr. & Frém.) occupy large areas of mountain slopes. Much of the mountain land is covered with bushes of several kinds, and aspens are common on the cooler and better watered slopes and along the watercourses in the mountains. In proportion as the soil-moisture conditions improve, the numbers of species and abundance of individuals of grasses and herbaceous flowering plants increase. The water resources are discussed later. A careful and exhaustive general treatment of these physical characteristics may be found in Aldous and Deeds' report [7] and need not

[7] UNITED STATES DEPARTMENT OF THE INTERIOR. AGRICULTURAL UTILITY OF UNRESERVED PUBLIC DOMAIN IN NEVADA. [U. S. Geol. Survey, Agr. Div.] Memorandum for the Press. 26 p., illus. 1926. [Mimeographed.]

be repeated here. Enough has been said, with the help of the maps, to set forth the general physical background of the problem.

It should be kept clearly in mind that the physical conditions set limits that are practically impassable upon the possible uses which may be made of the land. The very small production of any usable "crop" of which the land is capable not only sets a low limit on its sale and rental value, but a still lower limit on the amount of expenditure the user is warranted in making to improve its productivity. One can not spend much money to improve land that rents for a few cents per acre per year unless by so doing he increases the total output of the improved area enormously.

THE FORAGE RESOURCES

Data sufficient for the accurate and complete presentation of the forage resources of Nevada have never been obtained. If an attempt be made to assemble the available information, the data that must be used are found in several sorts of publications and reports. Botanists (*9*, *11*, *12*, *28*), zoologists,[8] and ecologists (*24*, *25*, *26*, *35*) have published maps which show plant and animal distribution, life zones, or ecological subdivisions. Altitude, precipitation, and temperature maps help in determining boundaries, since all of these factors are closely interrelated.

Geological papers frequently tell something about the more conspicuous or characteristic plants of the regions geologically described, and recent topographic maps issued by the United States Geological Survey show certain types of plant cover (*4*). Water-supply papers use certain plants as indicators of the depth of underground water, and they map the distribution of these indicators in considerable detail (*6*, *8*, *13*, *19*, *20*, *31*, *32*).

Certain range forage-plant studies have been carried out by experiment station workers and published in bulletins (*15*, *16*) or in technical magazines. Such studies usually consider nothing but the relative importance of certain named species adapted to particular uses. They occasionally name associated plants but tell comparatively little about their distribution and density.

Careful surveys of the forage resources have been made in most of the national forests, and the maps and reports, though not published, may be consulted.[9] Much valuable information as to plant cover in Nevada has been collected by the conservation branch, agricultural division, of the United States Geological Survey, which has been published in a preliminary report.[10] All such information is reliable and important, but none of the areas so treated has been selected with the idea of its being a representative sample. Results of the study of such detailed areas may be used as guides for the interpretation of less accurate and more generalized data.

Particular attention is called to the maps contained in the report of the Public Land Commission (*23*) and in the report made by Aldous and Deeds.[10] They show certain similarities and differences to each other and to the map that follows. (Fig. 3.) Neither of

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[8] BAILEY, V. LIFE ZONE MAP OF NEVADA. [Unpublished office copy.]

[9] UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE. RANGE CLASSIFICATION REPORTS OF THE NATIONAL FORESTS OF NEVADA. [Unpublished office reports on file in Forest Service.] 1922.

[10] See footnote 7, p. 7.

the earlier maps attempts to show anything but the way the range lands were being used at the time the data were collected. They have the effect of unintentionally implying that the use depicted is the only possible use, or the best use. The fact that they disagree noticeably shows that such an interpretation was not intended and is unwarranted, since the use has changed considerably in the twenty-odd years between the two reports.

FORAGE-PLANT ASSOCIATIONS AND THEIR DISTRIBUTION

Forage-plant associations must be based upon their forage-plant content. Such an association is, of necessity, an assemblage of a limited number of species of plants having a fairly well-defined common distribution area, similar possible uses, and nearly uniform grazing capacity. It must be easily distinguishable by some well-known species or set of species after which it is usually named. The area covered by such an association can be mapped and generalizations can be drawn from the map.

Notwithstanding the importance of such data in a study of this kind, no attempt will be made here to present anything but a generalization, some approximate measurements, and a map of the distribution of the principal forage-plant associations. (Fig. 3.) This map is on a small scale, much generalized, and diagrammatic, showing merely the major forage-plant associations found in the State. It is a summary of the available data. Some of the information was on a large scale and gave details that are not necessary here and that could not be shown on a map of this scale. For other parts of the map the available data were much less adequate. For this reason, important special areas are not shown on the map but are reported in Table 2 under some group of which they are assumed to be a part.

The principal kinds of forage plants found in these plant associations have been discussed in detail in the publications listed and will not be repeated here. Some generalizations concerning the associations are given here, and details are given in Table 2.

Five major range plant associations are listed in Table 2 with the principal important facts related to them. Two of these, the forest association and the creosote bush association, are of comparatively little importance, from a grazing standpoint, notwithstanding the large area covered by the latter.

The forest association is productive, has a large variety of valuable feed, is well watered, and has a high grazing capacity for the short period in which it may be grazed, but on account of its very limited area (a little over 500,000 acres) its relative importance for grazing is small.

The creosote bush area,[12] though containing over 4,000,000 acres, is relatively unimportant from the standpoint of production. Practically no sheep and probably less than 5,000 head of cattle are run on the area. The principal drawback is the lack of permanent stock water, though the feed is scanty and mostly poor. Both of these conditions arise from the very small amount of precipitation, which

[12] The exact equivalent of the "Southern desert scrub" of Shantz and the "Lower Sonoran Zone" of the U. S. Biological Survey writers as applied to Nevada (25).[13]

[13] BAILEY, V. Op. cit. See footnote 8.

averages less than 5 inches per year. The soils of the level basin floors within this area, where not too alkaline, are very fertile, and temperature conditions are extra favorable for crops. Hence, where

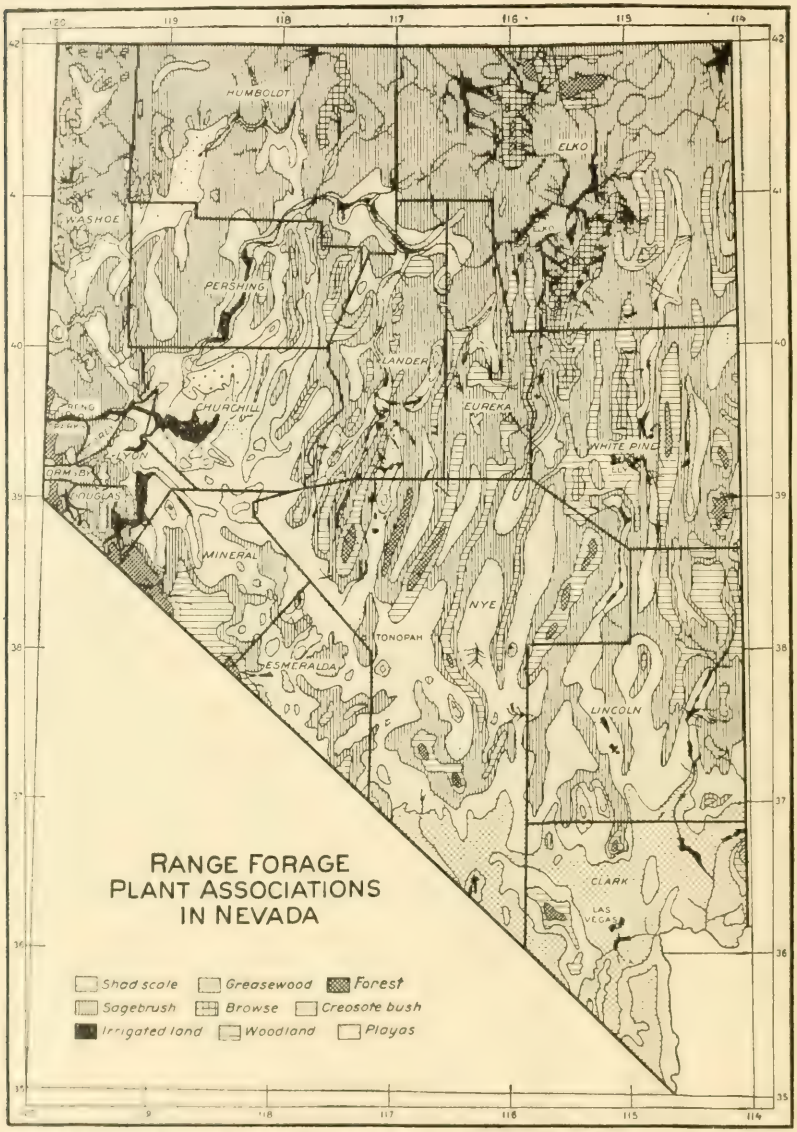

FIGURE 3.—This diagram is designed to show the approximate extent and geographic distribution of the areas covered by the major associations of forage plants upon which range livestock graze in Nevada. The playas have no plant cover of any kind, and the irrigated land is in crops. In estimating the area of each type the greasewood area was added to the shadscale and the browse to the woodland area, as explained in the text

sufficient irrigation water is available, conditions for crop farming are very good. A few small areas having a limited supply of artesian water are known within the area covered by this association. The

TABLE 2.—*Summary of the available data concerning the principal range forage-plant associations in Nevada*

[The playas shown on the map (fig. 3) have no plant cover of any kind and the irrigated land is in crops. In estimating the area of each type the greasewood area was added to the shadscale and the browse to the woodland area]

Item	Creosote bush association	Shadscale association	Sagebrush association	Woodland association	Forest association
Other published names (and authority).	Southern desert shrub (Shantz) (*25, 26*) and Covillea belt (Tidestrom) (*28*).	Lower part of northern desert shrub (Shantz) (*25, 26*) and sagebrush belt (Tidestrom) (*28*).	Upper part of northern desert shrub (Shantz) (*25, 26*) and sagebrush belt (Tidestrom) (*28*).	Piñon-juniper woodland (Zon) (*35*) and piñon belt (Tidestrom) (*28*).	Yellow pine forest or belt (Zon) (*35*), (Sampson) (*24*), (Tidestrom) (*28*), and timbered belts of higher levels.
Identifying plants	Creosote bush (Covillea tridentata).	Shadscale (Atriplex confertifolia).	Big sagebrush (Artemisia tridentata).	Junipers (Juniperus spp.) or piñon (Pinus mono phylla).	Pines (Pinus spp.), firs (Abies spp.), and mountain-mahogany (Cercocarpus spp.).
Other conspicuous plants that may range more widely.	Big rabbit brush (Chrysothamnus graveolens); Joshua tree (Clistoyucca brevifolia); horse brush (Tetradymia spp.); arrowweed (Pluchea sericea); cacti (Opuntia spp. and others); jointfir, Mormon-tea (Ephedra spp.); mesquite (Prosopis glandulosa).	Big rabbit brush; Joshua tree; horse brush; snakeweed or matchweed (Gutierrezia sarothrae); Bailey greasewood (Sarcobatus baileyi).	Hop-sage (Grayia spinosa); horse brush; small sagebrush (little sage) (Artemisia nova?); wild-rye (Elymus condensatus); blue-bunch wheatgrass (bunch grass) (Agropyron spicatum).	Buckbrush or snowberry (Symphoricarpus spp.); sagebrush in scattered areas; junipers, three species.	Aspen (Populus aurea); chokecherry (Prunus spp); wild plum (Prunus spp.); snowberry (buckbrush); willows (Salix spp.); alder (Alnus tenuifolia); many grasses and herbs.
Forage plants of importance in the association.	Fanscale saltbush or desert sage (Atriplex polycarpa); bur-sage (Franseria acanthicarpa) black brush (Coleogyne ramosissima); fourwing saltbush, often known as chamiza (Atriplex canescens); numerous spring annuals like California poppy (Eschscholtzia spp.); Indian wheat (Plantago spp.); Eriogonum spp.; annual grasses.	Little sage (Artemisia nova?); winter fat or white sage (Eurotia lanata); black brush; hop-sage (Grayia spinosa); wild-rye; fourwing saltbush; blue-bunch wheat grass; saltgrass (Distichlis spicata); alkali sacaton (Sporobolus airoides); spring annuals.	Little sage; winter fat; hop-sage; bud sagebrush (Artemisia spinescens); little rabbit brush (Chrysothamnus puberulus) wild-rye; rice grass (sand grass) (Oryzopsis hymenoides); blue-bunch wheat grass; galleta grass (Hilaria janesii); wheatgrasses Agropyron spp.); many annual and perennial herbs.	Aspen; bitterbrush (Purshia tridentata); blue-bunch wheat grass; other perennial grasses; many herbs; scrub oaks (Quercus spp.).	Mountain-mahogany (Cercocarpus spp.); aspens; snowberry (buckbrush); service berry or shadblow (Amelanchier spp.); elder (Sambucus spp.); bush (shrubby) cinquefoil (Dasiphora fruticosa); wild-rye; many species of grasses and herbs.
Approximate area covered	4,100,000 acres	20,800,000 acres	32,500,000 acres	8,500,000 acres	550,000 acres.
Total area of the State covered.	5.8 per cent	29.6 per cent	46.3 per cent	12 per cent	0.8 per cent.
Area of the association in national forests.	None	1.5 per cent	4.8 per cent	29.4 per cent	69.6 per cent.
Extreme altitude range above sea level.	2,000 to 3,500 feet	3,000 to 5,000 feet	4,500 to 6,500 feet	6,000 to 7,000 feet	Over 7,000 feet.

TABLE 2.—*Summary of the available data concerning the principal range forage-plant associations in Nevada*—Continued

Item	Creosote-bush association	Shadscale association	Sagebrush association	Woodland association	Forest association
Approximate limits of average annual precipitation.	Under 5 inches	Under 10 inches	10 to 18 inches	15 to 20 inches	Over 20 inches.
Season in which forage may be used.	Yearlong, where stock water is available.	Yearlong for cattle, winter for sheep.	Yearlong in places for cattle; mostly spring and fall; spring, fall, and winter for sheep.	Yearlong in south-central part of State for cattle; elsewhere spring and fall. Mostly spring and fall for sheep; some summer feed.	Summer feed for both cattle and sheep.
Present utilization	Only a few cattle	Cattle and sheep, at different places.	Much competition between cattle and sheep in utilization of this feed, especially in south-central part of the State.	Some competition in utilization, both cattle and sheep.	Both cattle and sheep use it under control of Forest Service.
Sources of stock water	Wells and springs, few and widely scattered.	Wells, springs, streams, and snow; much development possible.	Wells, springs, streams, and snow; considerable not yet developed.	Springs and streams, scanty in more southerly parts; poorly distributed over much of the area.	Springs and streams mostly plenty and well distributed. Considerable water that originates in this area is piped out to towns.
Temperature: extreme range recorded.	7° to 117° F	−38° to 108° F	−41° to 106° F	−25° to 105° F	−16° to 105° F.

rough mountain ridges scattered through the area usually have better feed of the higher (in vertical distribution) associations, but on account of lack of stock water these areas are rarely grazed.

In the Atlas of American Agriculture, Raphael Zon (*35*, p. *8*) says:

> Over thousands of square miles piñon-juniper and sagebrush alternate, the former occupying the rough, broken country and the shallow stony soil, while sagebrush occurs on the more level ground, which has a deep, uniform soil. The area of land occupied by piñon-juniper, especially in the Great Basin, is very great. * * * The piñon-juniper belt is characterized by hot dry summers, the annual rainfall being less than 20 inches.

The piñon-juniper area that Zon mentions exactly corresponds with the woodland association named here.[14] It covers about 8,500,000 acres in Nevada (12 per cent of the land area), but its carrying capacity, is hardly as great as might be expected from an area receiving as much precipitation as it does. The shallow soils and the open porous nature of the underlying rock are probably responsible for this condition. Though most of this association is on the mountain slopes and often covers the tops of the lower ridges, the feed is scattered and never very heavy, and the area is poorly watered. Even within the Toiyabe National Forest, the supervisor reports considerable tracts of woodland as practically useless because of insufficient stock water, and this condition exists in other mountain ranges in the same region. Farther north in the State the conditions in the woodland association are not so trying, and it furnishes its quota of the summer feed.

Two other forage classes used by the forest officials [15] are "aspen" and "browse." Aspen-covered areas range all the way from the cooler and higher parts of the sagebrush belt to the upper timber-covered slopes of the higher mountains. "Browse" is a convenient term for bush-covered ranges. It may occur anywhere above the sagebrush belt in the mountains. Over many of the mountain ranges in the State not in national forests these two types undoubtedly occur, but the details of their distribution are not known. Such areas have been classified on the maps as "woodland"; hence these two classes have been added to the woodland association. Together these two types, here treated as subtypes, cover a little over 1 per cent of the total land area.

The remaining two associations taken together constitute what Shantz calls the "northern desert scrub" (*25*). Thirty-two and one-half million acres, or nearly half the land area of the State (46.3 per cent), is in the sagebrush association. The area is characterized by level to gently rolling surface with deep fertile soil. Generally speaking, it is poorly watered for range use. This area furnishes most of the spring and fall grazing for both sheep and cattle, considerable of the winter grazing for sheep, and nearly all of the yearlong grazing for cattle in the south-central part of the State, where yearlong grazing of cattle is possible. Such cattle usually get considerable protection and some grazing in the lower edges of the woodland belt during the winter. The association formerly had

[14] It is called the "pinyon belt" by Tidestrom (*28*), the "pinyon juniper woodland" by Shantz (*26*), and the "pinyon-juniper belt" by Sampson (*24*).

[15] See footnote 9, p. 8.

a rather high carrying capacity for this general region, before it had been overstocked for years and badly eaten out. Many of its shrubs furnish good feed, and it had a rather thick cover of several long-lived, perennial bunch grasses that were excellent feed and well adjusted to the environment. They were the best forage plants of the region. Much damage has been done to all these best forage plants by long-continued overgrazing. Persistent, long-continued care and considerable expense will be required to bring this association back to its former productivity, but such a result is possible and may ultimately be obtained.

Scattered over the sagebrush area, especially in the northern part of the State and near the upper edge of that belt, comparatively large patches of wild rye occur. Formerly these were much more extensive. Many of them are used as hay meadows now, most of which are irrigated or subirrigated. Considerable areas within the Humboldt National Forest partly of this character and partly with a cover composed of other grasses are classed as "grasslands." The same name was used for the grasslands outside the forests. These areas are very important on account of the feed they produce, but the patches are too small to show on the map. The areas inside the forests classed as "meadows" and "open weed range" are even smaller. They have all been included in the sagebrush association on the map and in the summary table. This arrangement is not entirely satisfactory, but it seemed necessary. Taken all together, these grasslands cover a little over 1 per cent of the total area of the State.

Lying at levels just below the sagebrush and occupying the floors and lower slopes of all the basins, on soils that are usually heavier, drier, and more alkaline than those of the sagebrush area, is the shadscale association. The total area covered is about 20,800,000 acres, which is 29.6 per cent of the land area of the State. This association furnishes a small quantity of the spring and fall feed for livestock, usually taken as they travel over it, and much of the winter feed for sheep. For the most part the feed is not particularly good, except on the areas covered by winter fat and little sage, which overlap the upper part of this association and the lower part of the sagebrush association. Areas covered by Coleogyne, which overlap the lower edge of this association and extend into the creosotebush area, also furnish moderately good feed. The shadscale[16] itself furnishes much of the feed.

The greasewood area shown on the map is included in the table with the shadscale association, which is merely a way of choosing the lesser of two evils. This greasewood area is covered by a composite group of scattered alkali-enduring, water-requiring shrubs and certain grasses that have about the same requirements, like saltgrass, alkali-sacaton, reed grass, etc. In very wet places tules and rushes come in, and in others, where the alkali is not so strong, bunches of wild rye may occur. The shrubs are not very important sources of feed, though they are used to some extent, but the grasses furnish

[16] Griffiths (11) calls this plant spiny saltbush; it is one of the saltbushes—*Atriplex confertifolia*. The name shadscale probably originated in Utah, though in some of the older bulletins it was applied to *A. canescens*, a mistake the present writer once followed. That plant is now usually called by the Spanish name, chamiza.

considerable feed. These greasewood areas are mostly associated with shadscale, but they may be found below it in the creosote-bush association or above it in the sagebrush area. The group is relatively too unimportant to be ranked with other major associations, and since it is mostly used with the shadscale association it is here combined with that area.

Besides the range areas just discussed, three other major land classes are shown on the map and in the tables, which must be treated briefly for completeness. These are the irrigable lands, the playas, and the barren or waste lands of the high mountain peaks and cliffs. Little or none of the land can be successfully dry farmed.

It has been tried in nearly all parts of the State, but usually by settlers with little knowledge of the proper cultural methods, whose efforts were doomed to failure from the outset. Even with proper cultural methods there are relatively few areas in which the quantity of precipitation, the length of the growing season, and the soil conditions are so combined as to permit the practice of dry farming with reasonable success.[17]

All the lands reported as irrigated or irrigable were included in this class. The resulting area is about 1,600,000 acres, or approximately 2.3 per cent of the land area of the State. This figure is almost three times the area assessed as irrigated or subirrigated by State and county officials (592,371 acres). The crop-land area reported in the 1925 census is about the same (533,614 acres) as the assessed irrigated area, which is a fairly good check on the accuracy of the assessors' figures, since all the crops grown in the State are produced on irrigated or subirrigated land. It is therefore safe to say that the irrigated area shown on the map (fig. 4) is considerably exaggerated, though some such treatment is necessary to make its presence apparent in the large areas of grazing land that dominate the picture.

The irrigated lands are nearly all used in direct connection with the range-livestock industry. Of the 362,552 acres of harvested crops reported in the 1925 census, 332,682 acres (nearly 92 per cent) produced some sort of hay and 9,174 acres produced other forage, most of which was used as winter feed for range livestock that must be fed for a short time when range feed is not available. Although some of the forage produced may have been sold or used for farm stock, it is safe to say that enough of the crops other than forage, grown on the irrigated lands of stock ranches, were used by the families and farm stock on such ranches to more than balance all the hay sold and that used by farmers without range-stock interests. So at least 85 per cent of the crops produced in the State were used in the range-livestock industry. Two-thirds of the area classed as irrigable was not irrigated, but was used as additional pasture lands, sometimes of high-carrying capacity, along with the range lands.

Scattered over the State, in the bottoms of the bolsons, or valleys without exterior drainage, are many absolutely bare areas of varying size, the bottoms of old lakes that have dried up, called playas. These playas are common in all regions of inclosed drainage such as the Great Basin, and the area of such land is relatively large in Nevada (1,400,000 acres, or 2 per cent of the land area), where they are sometimes referred to as "slick deserts."

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[17] See footnote 7, p. 7.

These areas produce no feed. Studies made by the United States Geological Survey indicate that they are areas from which underground water that rises to the surface is continually evaporating. This process has resulted in such large accumulations of alkali in the soils that no known plant will live on them.

These playas are level for long distances. On some the surface when dry is hard and full of cracks; on others the dry surface is finely powdered and not so hard. When wet they are impassable to vehicles of any kind and deserve their local name. Except for very limited deposits of certain minerals, they have no use and are often much in the way, since one must go across or often around them at great expense of time and effort. Digging near the margins has demonstrated that water is to be had near the surface, but it is usually very alkaline.

On the tops of most of the mountains and often along the sides of canyons are rocky cliffs and peaks that produce little or no forage, and what little they do produce is inaccessible. In the Sierras there is a small area in Nevada covered so densely with certain coniferous trees that no forage plants are produced. The total area of such barren land is a little over 750,000 acres, or 1.1 per cent of the total land area of the State.

GRAZING CAPACITY

The numbers and kinds of stock grazed and the length of the grazing season are accurately known for each administrative subdivision of each of the national forests. These data are on record for a long series of years, so that a long-time average of the number of days feed per animal unit produced on known acreages of standardized types of forage may be calculated for each of the forests in which the forage types have been mapped and measured. In the few forests in which this mapping has not yet been completed, somewhat less exact but reasonably accurate estimates could be made.

The area of land in harvested crops in 1924 and the kinds and yields of these crops are reported for each county of the State in the agricultural census. From the total crop yields of forage plants the number of days of feed per animal unit produced by the irrigated lands can be calculated.

Mountain lands, presumably having forage similar to that in corresponding localities in the national forests, have not had their forage types mapped and measured. Consequently averages obtained from the forests can not be applied to these areas. Nor are the numbers and kinds of animals grazed on these lands definitely known.

The forage types covering by far the largest part of the land area of Nevada—that outside the forests—are not found inside the forests, and the grazing capacity of each has never been measured.

It is, therefore, evident that any attempt to estimate grazing capacity for each forage-plant association can not now be successful, and that the total grazing capacity of the State can not be obtained in this way.

A circular of the United States Extension Service entitled "An Estimate of the Forage Produced in the Eleven Western States" [18] contains among others an estimate for Nevada as a whole. It offers a method for "evaluating the feed resources of the various agricultural areas within the States" that can be used by county agricultural agents and others interested. This method can be applied to small as well as large areas and may be described as follows: The total quantity of feed used in an area is derived from five sources—harvested crops, plowable pasture, controlled range, national forests, and uncontrolled range. The quantity of feeds derived from each of these sources except the uncontrolled range is either accurately known or can be closely estimated from available records. If the numbers and kinds of animals produced in the area are known, the number of days' feed required to sustain them for a year may be calculated and allocated to the five different producing areas, if the acreage of each area is known. As has been stated, all the details are known for the irrigated crop land and for the national forests. The areas of the controlled pasture and range may be ascertained from the census, and the uncontrolled range is the remainder. The feed produced on the controlled pasture lands can be closely estimated, and what is not otherwise accounted for is furnished by the uncontrolled range.

For Nevada the following results were obtained by this method: Fifteen per cent of the feed used was produced by the (irrigated) harvested crop land (about 400,000 acres), 4 per cent from plowable pasture land and 8 per cent from the controlled range (the two together estimated at about 5,000,000 acres), 11 per cent from the national forests (4,750,000 grazable acres), and the remainder, or 62 per cent, from the uncontrolled range (about 56,500,000 acres). This allows 3,600,000 acres for barren and unproductive lands, which is a reasonable estimate.[19]

THE WATER SUPPLY AND ITS USE

The business of producing livestock in Nevada—one of the major permanent industries of the State—is absolutely dependent upon the proper utilization of the State's water resources. Over at least half of the area of the State, and that half the one which produces the most and the best feed, feeding of range livestock for a longer or shorter period in the winter is a necessity determined by climatic conditions. This fact is basic to the industry and has been taken for granted almost since the business started. The present type of organization of the livestock industry is a direct outgrowth of this fact. It has been the practice for many years to assume that if the operator had irrigated land enough to produce the hay required to carry 100 head of cattle through the winter-feeding period he could run 100 head on that range, because the outside range was believed to be ample to carry the stock through the remainder of the year.

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[18] MERRITT, E. FEED RESOURCES OF 11 WESTERN STATES, 1925. U. S. Ext. Serv. Circ. 20. 1926. [Mimeographed.]

[19] In the opinion of the writer the area shown as controlled pasture and range is several times too large. It is doubtful if the fenced pasture lands in Nevada aggregate over 1,000,000 acres (not including irrigated crop lands). They can hardly be credited with producing 12 per cent of the total feed. If this judgment is correct the percentage of feed produced by uncontrolled range would be greater, the area of such land greater, and the animal-unit-days feed per acre from this source a little greater.

Need of winter feed has made the production of hay in sufficient quantity to supply this need the principal function of the irrigated lands, for two reasons: (1) The range lands can be used best when supplemented with a reserve supply of feed which may be most conveniently produced on irrigated lands, and (2) the demand for winter feed furnishes a market for the hay that is one of the most easily produced crops of these lands. Virtually all the irrigated lands are used in connection with the livestock industry, usually as part of the stock ranches themselves. Only a very small part of the total irrigated area of the State is being used for ordinary crop farms. Census figures do not show this relationship, because they list all ranches as "farms" and include all owned range land in "land in farms."

Permanent watering places are necessary on stock ranges. Perhaps the most striking feature of the ranges of Nevada to an observer who is well acquainted with other arid and semiarid range lands is the long distances which separate the watering places. This is to be expected in areas of scanty rainfall like that covered by the creosote bush association (fig. 3); but in other States semiarid range lands having grazing capacity comparable with that of most of Nevada have many more developed watering places than are to be found in Nevada, and they are much closer together.

The suggestion can hardly be seriously made that Nevada stockmen do not know of the water resources of the State or appreciate the importance of proper water distribution over their ranges or that they are unwilling to pay for the development of such a vital necessity. There is abundant evidence, including that in several Government publications, to prove that considerable underground water is available which might be but is not used.

Nor can it be argued that the ranges are as yet understocked and that the water is not needed. Evidences of long-continued overstocking abound on the ranges, and the literature treats of the subject in many places.

In the opinion of the writer the reason for the lack of development of stock water, which is conspicuous all over the State, is the fact that control of stock water in most cases does not control the range surrounding it. When the ranges were occupied by cattle alone, such privately owned watering places did exert a measure of control over the surrounding public range lands, just as it did and still does in other regions of the arid Southwest. This control disappeared when it was learned that sheep could be run over such ranges in the winter wherever sufficient snow could be found to supply them with water.

Control of the stock water is without doubt an important factor in many parts of the State, but the writer surmises that it is the control of the irrigation water and the irrigable land upon which the hay for the winter feeding is produced that to a much greater degree dominates the situation, at least in the upper Humboldt Valley, and brings about certain undesirable conditions.[20]

Ever since it was learned that sheep could use the snow for water during the winter, nomadic sheep have been the bane of Nevada

[20] This situation was discussed some years ago by Adams (1), though he seems to have overemphasized the importance of the control of stock water.

cattlemen. Probably more thought has been given to this condition than to any other phase of the livestock business, and more different kinds of abortive attempts have been made to control nomadic sheep in Nevada than in any other range State.

It follows that if any better adjustment of the business to the environment is to be brought about, the method of approach to such a change must be by way of legislation affecting the grazing use of the land, since there is little probability of a change in the climatic conditions involved.

To present the extent and distribution of the water resources of the State and their utilization, a diagrammatic map is given (fig. 4) which shows the irrigated land and the allotted stock-watering places. The sources from which the data were obtained and the degree of accuracy of the map are explained below.

With the other dry-land States, Nevada was granted control of its natural waters by the law of 1866 (p. 32), and for many years its citizens appropriated irrigation and stock waters (along with those used for mining and smelting) without any very definite regulations.

In 1905 the State legislature passed a law establishing a method of obtaining the right to put waters to beneficial use. Water appropriations that were already established at the time of the passage of this act were recognized as vested rights, for both irrigation and stock water. Future appropriations, under this law, are to be made through the State engineer, who keeps a record of all official allotments.

Since much of the irrigation water is held under these vested rights some of which are not yet on record in the engineer's office because the rights have not yet been definitely delimited,[21] a copy of his records would show only a part of the land actually irrigated under legally appropriated water. This is true in lesser degree of the stock waters held under vested rights.

The best map of the irrigated lands of Nevada is that published in the report on irrigation in the 1920 agricultural census. Upon this map as a base, the positions of the stock watering places in the State allotted up to 1927 have been entered, and a reduced copy of that map constitutes the impressionistic picture given here. (Fig. 4.) A perfectly accurate map of this kind would show a few additions to and slight changes in the irrigated areas here depicted (which were rather liberal estimates) and more dots showing stock watering places, but the general picture of distribution would be essentially the same as this. A comparison of this map with the land-tenure map (pocket map No. 1) will show to what extent the irrigated lands are used for livestock production and how much is used by farmers (see p. 28).

THE CONTROL OF THE LAND AND ITS UTILIZATION

Nevada was part of the area ceded to the United States by Mexico in 1848. Settlement of the area that now constitutes the State began shortly after the discovery of gold in California, almost wholly in consequence of that discovery, and in two ways.

[21] The condition of uncertainty as to area irrigated and water allotted arises from the fact that the law establishing vested water rights did not require that each be determined and recorded with the State engineer within a specified time. A similar condition exists in parts of Colorado, with consequent uncertainty as to the limits of certain vested rights.

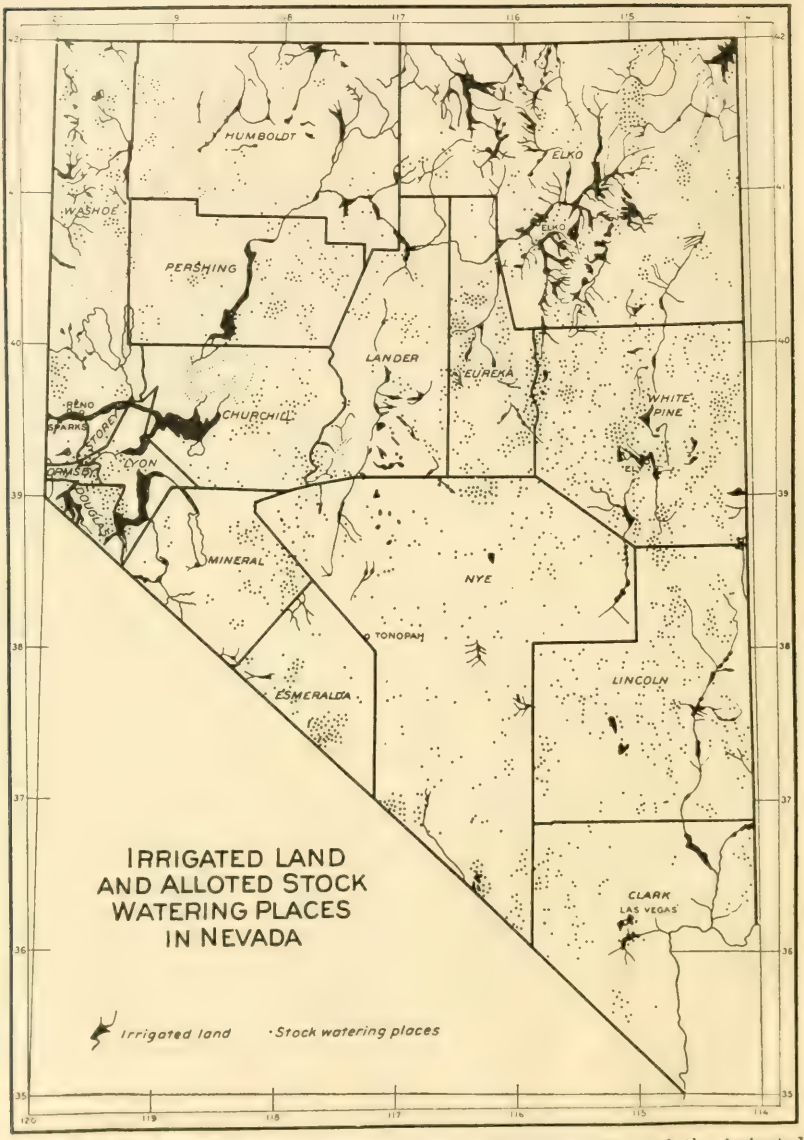

FIGURE 4.—The base map used is the diagrammatic presentation of the irrigated lands as published in the irrigation report of the 1920 census. It is known to be slightly exaggerated. Some changes have occurred in the last 10 years, but it is believed that this is still the most accurate information available for a map of this size. Upon this base has been entered the approximate distribution of allotted stock-watering places as recorded in the State engineer's office to 1927. Other allotments have been made since, and there are some stock watering places held under vested rights that have not been recorded

The principal land route to the gold fields followed down and up two of the most important stream valleys of Nevada, the Humboldt and the Truckee, hence what has since proved to be some of the best land was known to all who passed, because it lay beside the main traveled road. Stations along this road were an immediate necessity, and settlement began at convenient points in the Humboldt Valley and in other valleys near the base of the Sierras.

Soon after prospecting for gold began in what is now California, valuable mineral deposits were found on the east slopes of the Sierras, and mining settlements were made beside the prospect holes that produced valuable ore. Thus, mining and transcontinental transportation were established and were then, as now, two of Nevada's principal industries.

Stock feed was abundant in the Humboldt Valley and in many of the basins. Pasture grasses were plentiful on subirrigated lands, and many "rye patches" were ready to be cut for a winter supply of hay. The transcontinental traffic of the time brought with it, more or less as a by-product, the first of the animals that started the third great industry of the State—range-cattle production. Although the range livestock industry started slowly, it grew steadily, and is now the second largest source of taxes in the State.

From the original cession until to-day—a period of about 80 years—the lands of Nevada have been easily obtainable under one or more of the Federal land laws. But in all that time only a little over 4,000,000 acres—less than 6 per cent of the 70,000,000 acres of land in the State—have passed into private ownership, if the lands granted to the Central Pacific Railway Co. as a subsidy are excepted. Over half of the land in private ownership was acquired by the indirect method of purchasing school lands, as explained elsewhere. (See p. 33.)

For many years range stockmen claimed that the lands of the Great Plains—an enormous area lying west of a generally north-and-south line from central North Dakota to San Antonio, Tex., and stretching to the Rocky Mountains—was good for nothing but range grazing. It was generally believed that the rainfall was insufficient for crop farming and would always be so. Arguing from this assumption and the fact that these lands were then in use as range grazing lands, they urged that the lands be transferred to them in large bodies, and they went to great lengths to attain this end. That they could never agree on how the transfer should be made probably constituted one of the principal reasons why no Federal legislation designed to fit the conditions was ever passed. Later experience has demonstrated that their assumptions and contentions were incorrect, since much of the region is now in crop farms and most of it is capable of being used as dry-land crop or crop and livestock farms.

That such a condition does not exist in the case of Nevada is believed to be demonstrated by the analysis of the existing and potential utilization of its lands that is here presented. Recognizing that a more intensive use of the land might arise, great care has been exercised, in classifying the land holdings into utilization types, that crop farming should be given the advantage of any doubt over range-grazing uses.

METHODS USED IN THIS STUDY

Data concerning the area of land owned and the use made of it the previous year by all the landowners in the State (outside the towns) were obtained from the county assessors. The area and distribution of the lands leased from the railway company and the names of the lessees were copied from the records of the company.[22] The records of all the stock permitted to graze in the national forests and their distribution in the forests were obtained, as well as the range classification and operative subdivisions of the forests. A considerable part of the State was visited. State records of the disposal made of the school lands and of the administration of the water laws were studied and used. State and Federal officials in direct touch with the use of the lands were consulted, as were numerous stockmen who are using these lands. The literature was assembled and studied, and the developmental and legal phases were considered.

The land data thus obtained have been assembled and the ownerships classified on the basis of the use made of the land in the year to which the records apply—1926. The summary of this work is presented on the land-tenure map (pocket map No. 1) found in the pocket at the back of the bulletin. Further explanations of methods used and generalizations as to major deductions follow in the text, and some of the details are shown in the tables.

The major subdivisions of the State were on the Land Office maps. The position and extent of the national forests and Indian reservations were known, as well as the approximate limits of the railroad land-grant belt. The assembled data gave the location and amount of the privately owned land; there are no longer any State lands, and there is only one small national monument. The remainder is all considered to be public domain, though a small part of it is held as uncompleted homestead entries.

The first step was to devise a classification that would fit the data and give an instructive picture of the situation when these data were assembled. The principal categories of such a classification had been suggested by the data themselves. The land users are stockmen or crop farmers. At times it was difficult to tell to which class a particular individual belonged. Some of the land is not used by its owners; such land is a part of the open range, and is grazed by range stock if it is used at all. A negligible part of the owned land is used for mining. These data indicated the two major classes of users—(1) range stockmen, (2) farmers—and a third group of owners which, for lack of any better name, was called miscellaneous.

The range stockmen automatically fall into three classes—producers of (1) cattle, (2) sheep, or (3) both cattle and sheep. It was necessary, for tabulating purposes, to set somewhat arbitrary limits to determine what should be called a cattleman, or a sheepman, or a farmer having range stock. A man who had as many as 50 head of range cattle was classed as a cattleman. The possession of more than 300 head of sheep caused a man to be classed as sheepman unless the list of the sheepmen (in the State brand book) showed that his sheep constituted a "farm flock." The fact that a man had a registered brand or was on the list of the active cattlemen of the State

[22] No means of learning about other kinds of leases were available (p. 29).

and had a permit to graze more than 50 head of cattle in the forest confirmed his classification as a cattleman.

To avoid classifying a "farmer with range stock" as a "range stockman," whenever a doubt in the matter arose, the man was placed in the farmer class. The resulting summaries give evidence that some of those listed here as farmers really consider themselves stockmen, and although they farm their lands, their most important source of income is livestock produced partly on the open range. It is thus shown to be almost certainly true that, by various incorrect but unavoidable interpretations of the available data, the total number of men and the area of the holdings of such men as consider themselves stockmen rather than farmers have been minimized. This reduction is believed to be small, but it is enough to insure against exaggeration of stockmen's numbers and holdings, a mistake the author was anxious to avoid.

Difficulties were also experienced with the "miscellaneous" class. The data were sometimes insufficient or conflicting. Assessors did not know, or what they said disagreed with what others thought was correct or what was shown by their own published annual reports. In all cases of doubt or uncertainity, the landowner and his land were classified in the miscellaneous group. Although the evidence sometimes suggested that considerable areas of privately owned land were probably leased to stockmen and used as range lands, so long as the data were insufficient to determine the use with certainty, such lands and their owners were classified as belonging to the miscellaneous group. In a number of instances it happened that the land shown on the assessor's plats (which were copied for study) was shown in his report under another name for which the equivalent was not known. Such acreages also went into the miscellaneous group.[23]

There is hardly any doubt that a considerable number of sheepmen, who neither own nor lease land in the State and who do not have permits in the forests, graze their animals on Nevada ranges. These methods and data omit all such users of the public domain. No method was readily applicable that would give reliable quantitative data concerning such operators.

Considerable talk about migratory or nomadic sheep was heard. The owners of such sheep were nearly always said to live in an adjacent State. There is no doubt that some sheep from outside the State do come in, and it is certain that some Nevada sheep go out of the State for feed. It is generally believed that such interstate movement of stock (mostly sheep) is a necessary condition of the best use of the available forage, though there is reason for believing that its importance has been considerably overemphasized. The undesirable consequences of such unregulated nomadism are well known. It is recognized that many of these sheep belong to operators who have established possessory and other rights in Nevada, but they do not confine their stock to the areas associated with such rights, and since the range is open and free to all comers, there is

[23] In some of the counties containing national forests the assessor's plats did not show the location of privately owned (alienated) land within the forest. This was learned long after it was too late to copy these data from the forest records. This gave a number of names of permittees for whom no owned land could be found. Some of these were people living in town, some were Indians whose allotted land is not taxed, and some probably held rented land (p. 30).

no means of regulating their actions. But it makes little difference to the permanently located cattleman, who has investments in ranch property, whether the nomadic sheep that appropriate the feed on lands surrounding his watering places which is needed by his cattle belong to a wandering "tramp" sheepman or to a Nevada stockman with possessory rights. Without the feed he is powerless to carry on his business, and his investment is valueless. If the sheepman ultimately buys his ranch it is at once changed from a home occupied by a family into a temporary sheep camp.

From this explanation it follows that the actual number of range stockmen of all kinds in Nevada may be and probably is somewhat greater than the 923 shown in Table 4. The figures showing numbers of forest permittees and lessees of railroad-grant land are correct, as are the numbers of permitted stock and the acreages of land leased from the railroad company. Some duplication in permittee numbers was unavoidable, because in one class many of the men held permits for both sheep and cattle which were issued and enumerated as separate permits, although held by the same person.

On the map which gives a picture of the use made of the controlled land (pocket map No. 1) the areas in black (showing the controlled lands of farmers with and without range stock) and in red (miscellaneous—all kinds) are both exaggerated. A considerable part of the red and some of the black should be green or blue or yellow. The colors black and red were chosen in order to accentuate further these really insignificant areas when compared with the other colored areas and the large area of white—the public domain.

In only one way can injustice be said to have been done by this method. Although areas of "miscellaneous" and "farm" lands are small, the numbers of people listed under these terms are larger than they should be, and comparisons of such numbers should take this into consideration when generalizations are being attempted. (See explanation following Table 4, p. 30.)

In spite of the minor but unavoidable inaccuracies, the relationships shown by the ratios and percentages obtained by the study are believed to be entirely reliable, and the following generalizations concerning the relative importance of the various types of land control and use are warranted.

THE RANGE STOCKMEN

At least 16 per cent of all the landowners [24] in Nevada are stockmen whose principal business is raising cattle, sheep, or both. The number is somewhat dependent upon definition, but is safely between 750 and 1,000 individuals or companies. The number so classified here, using the method previously explained, is 923, of whom 572 raise cattle, 210 raise sheep, and 141 raise both cattle and sheep.

These men own about 68 per cent of all the privately owned land in the State.[24] Of the 923 owners, 103 (11.4 per cent) lease more railroad land than the whole group owns, and what they rent is over 98 per cent of all the railroad land rented.

It is of interest that the average holding of the cattlemen (approximately 2,250 acres) is about the same as that of the sheepmen

[24] Not including town property nor railroad land.

(approximately 2,400 acres) and that the operators who are handling both kinds of stock have average holdings nearly four times as large (8,500 acres). The sheepmen lease much more railroad land per man (34,700 acres) than the cattlemen do (13,900 acres), but not as much as the men who raise both sheep and cattle (61,150 acres).

These figures clearly demonstrate that the men who are raising both kinds of stock are much the larger operators. The class includes most of the large incorporated companies. Most of the smaller operators are those who produce cattle only, though a considerable number of the sheepmen have only one band.

These range stockmen (including all kinds) control about 81 per cent of all the controlled land in the State. Of this group, nearly half (47 per cent) hold permits to graze livestock in the national forests during the summer. These permittees own 94.1 per cent of all cattle and 98.7 per cent of all the sheep permitted in the forest, and they control (own or lease) nearly half (47 per cent) of all the controlled land of the State. In this group of permittees the men who handle both kinds of stock again constitute the dominating factor. The average forest permit of the cattlemen is about 175 head; the sheepman's average number is 3,500 head, while the corresponding numbers for the operators who raise both kinds of stock are 325 and 4,100 respectively.

The figures obtained do not show how many acres of the irrigated land are in stock ranches instead of farms. But a careful comparison of the water-resources map (fig. 4) with the land-tenure map (pocket map No. 1) will give a good idea of the relative proportions. It is safe to say that over half of the irrigated land of the State is in stock ranches; and the census report shows that much the greater part of the crop land—the irrigated land—produces hay, practically none of which leaves the State.

The tables demonstrate that much the greater part of the land area of Nevada—irrigated valley land, railroad-grant land, national forests, and open public domain—is used for the range production of livestock. They also show that a few large operators—less than 150 in number—each of whom raises both cattle and sheep, control over one-third of all the controlled land of the State and use at least that proportion of the open grazing lands.[25]

These figures disprove one generalization which has often been made and which is accepted as true by many of the stockmen. It is often stated that the only proper organization of a stock ranch in Nevada is one that will furnish (1) winter feed and some fall and spring grazing on the owned land of the ranch, (2) summer grazing under permit in the national forests, and (3) the remainder (possibly five or six months' feed) on the public domain.

There can be no doubt that an organization of this kind is a convenient one and one which, under favorable economic adjustments and on a large scale, may be profitable to the operator. But the

[25] Attention is again called to the comparisons presented in Table 1 (p. 4) as to the relative productivity of these arid range grazing lands. Acreages controlled by some of the larger operators seem very large to men accustomed to think of highly productive crop land, but the actual size of business of such men is not out of the common when compared with large ranches elsewhere. Two of the largest operators in the State, each of whom owns more than 90,000 acres, rents 450,000 acres of railroad land, and uses approximately 2,000,000 acres of public domain, run less than the equivalent of 12,000 head of cattle each. There are ranches in other States that run considerably more stock.

tables show that only a few of the ranches are completely so organized, since less than 10 per cent of the cattle and not over 75 per cent of the sheep go to the national forests. These percentages are both too large, since they show what percentage permitted cattle and sheep are of the total assessed number of range cattle and sheep for the State, and it is well known that numbers of assessed stock are rarely, if ever, the full numbers, and that a considerable number of "tramp" sheep are not taxed.

Not only is this general type of range-stock raising not the only possible one, but it is doubtful whether it is the most desirable one from the standpoint of anyone but the man who profits by it. The writer agrees with Adams (*1*) in thinking that, as it is at present exemplified, it is undesirable sociologically; and he is also reasonably certain that it makes for a relatively inefficient use of a large part of one of the State's major natural resources—the irrigable land and the associated irrigation water.

In support of the conclusion that such a condition exists in the northeastern corner of the State [26] and constitutes a separate and very different problem in land utilization, Table 3 has been compiled from the United States Agricultural Census of 1925 (*29*), supplemented by more recent detailed figures. It has been so arranged as to show the efficiency with which the crop land is now being used by the operators in these four counties as compared with the uses of such land in the other counties of the State.

TABLE 3.—*Data for a comparison of the relative efficiency of utilization of their crop land and water resources as made by the 4 northeastern counties of Nevada and by the other 13 counties*

COMPARATIVE ACREAGES, YIELDS, AND VALUES

Item	Unit	The 4 northeastern counties	The 13 other counties
Land area	Acre	23,514,240	46,771,200
Land in farms	do	2,430,459	1,660,127
Crop land	do	295,632	237,982
Land in hay (all kinds)	do	167,178	165,504
Area in alfalfa	do	28,804	111,851
Estimated yield of alfalfa hay [a]	Ton	48,679	268,442
Area in wild grass	Acre	106,612	21,446
Estimated yield, wild grass hay [a]	Ton	90,620	19,516
Area of all other hay	Acre	31,762	32,207
Estimated yield of all other hay [a]	Ton	34,303	43,802
Estimated yield of all hay [a]	do	173,602	331,760
Total yield of all hay	do	153,740	312,146
Crop land in other crops	Acre	3,047	25,541
Remainder of crop land (idle, fallow, etc.)	do	125,407	46,937
Value of all crops	Dollar	2,354,799	6,101,034
Value of all livestock	do	11,439,577	14,933,951
Value of all livestock products	do	1,490,900	4,180,503

[a] Estimated from weighted average acre yields for the counties included, using data obtained in 1929 for the 1930 census. Such detailed figures were not published in the 1925 census. The average yields per acre change very little from year to year.

[26] This expression is used (p. 48) to refer to the upper Humboldt Valley and its branches; the conditions are best exemplified in Elko County. In compiling the table, the four counties, Elko, Eureka, Humboldt, and Lander, were treated as constituting the region concerned. Of course, this is only a rough approximation for which census figures could be assembled.

TABLE 3.—*Data for a comparison of the relative efficiency of utilization of their crop land and water resources, etc.*—Continued

PERCENTAGE COMPARISONS

Item	Unit	The 4 northeastern counties	The 13 other counties
Crop land in hay	Per cent	56.55	69.54
Crop land in alfalfa	do	9.74	47.00
Crop land in wild grass	do	36.06	9.01
Crop land in other hay	do	10.75	13.53
Crop land in other crops	do	1.03	10.73
Remainder of crop land (idle, fallow, etc.)	do	42.42	19.72
Value of all crops	do	27.85	72.15
Value of all livestock	do	43.38	56.62
Value of all livestock products	do	26.29	73.71

AVERAGE YIELDS PER ACRE

Alfalfa hay in 1929	Ton	1.69	2.40
Wild grass hay in 1929	do	.85	.91
All other hay in 1929	do	1.08	1.36
All hay in 1929	do	1.04	2.00
All hay in 1924	do	.92	1.89

It should be remembered that the most valuable natural resources of Nevada are its irrigable land and its irrigation waters. Since only irrigable land can be cropped in that State, the census figures for crop land and its utilization give data for comparisons. Since by far the greater part of the crop land produces hay, a careful study of the area and production of each kind of hay and the average yield per acre are criteria as to the efficiency of use of both land and water. Unfortunately, the yields of the different kinds of hay were not obtained for the 1925 census, but the details for 1929 are now available and have been applied to the 1924 areas on the assumption that average county yields per acre do not vary materially from year to year. Since the principal agricultural industry of all the counties is the same and the products of this industry are closely comparable, the total values of the different agricultural products—crops, livestock, and livestock products—also indicate relative efficiency of the use of the land and water for agriculture.

Attention is called to some of the striking contrasts shown in Table 3. Though the four counties contain only about one-third of the land area of the State, they have about three-fifths of the land in farms and 55 per cent of the crop land, which also includes the irrigation water. Notwithstanding these advantages, the 4 counties have only 1,674 acres more land in hay than the 13 other counties and less than one-eighth as much land in other crops. Over 40 per cent of the crop land of the 4 counties was, for one reason or another, unproductive, whereas the corresponding figure for the 13 counties was less than 20 per cent.

Yet the 13 counties had nearly four times the acreage of alfalfa that the 4 counties had and produced five and one-half times as much alfalfa hay and about the same acreage of all other tame hay, with over one-fourth larger total yield. The acreage of wild-grass hay in the 4 counties is nearly five times that of the other 13, but the average yield per acre is somewhat less. Average yields and feeding

value of wild-grass hay are usually much less than those of alfalfa and somewhat less than those of other tame hays. The average yield per acre of all kinds of hay in the 4 counties was less than half that in the other 13, and although the hay acreage was greater the total tonnage produced in the 4 counties was only slightly over half that grown in the other counties. The better utilization of these natural resources is certainly desirable, and these 4 counties constitute one part of the State that might profit by a better organization and use of its irrigable land and irrigation water.

The writer also believes that the earlier method of estimating rate of stocking cattle ranches (p. 17) no longer holds good, as much of the spring and fall pasture land has been turned into hay land by a better use of the water supply, and the grazing capacity of the open range land has been depleted considerably by continued overgrazing. In consequence, the spring and fall grazing periods on pastures and ranges have been shortened without lengenthing the feeding period, and the number of cattle has been increased because of increased hay production. This results in an attempt to lengthen the summer grazing period to a degree that the area of this sort of feed will not carry.[27]

THE FARMERS

Twenty-seven per cent of all the landowners (1,550 operators) are crop farmers, though some of them (429 operators) run a few head of stock on the open range. They own about 355,000 acres of land, which constitutes only 8.1 per cent of all the owned land in the State. The average size of their farms is about 230 acres. Since most of them do not use outside range land and since land that is not irrigated can not be farmed, the greater part of the land in these farms is consequently irrigated or irrigable. Only a few of them have leased any railroad land in addition, and the amount leased raises the average size of the farm less than 10 acres. Forty-six of those farmers having range stock hold permits in the national forests, which supply summer feed for 1,067 head of cattle and 795 sheep. The cattle permitted constitute less than 2 per cent of all permitted cattle on the forests, and the sheep are 0.2 per cent of all permitted sheep.

From these figures it is safe to say that there have been few or no mistakes in the classification of these landowners as farmers. They use the range lands and national forests hardly at all. Their numbers and the percentage of the owned land that belongs to them show how unimportant farming (as most people understand the word) is in Nevada.

As will be noted by an examination of the land-tenure map, on which farm land is shown in black, appreciable areas of farm land are to be found in only a few places in the State. These black areas occur along the bases of the Ruby Mountains, around Lovelocks, around Fallon, near Reno and Carson City, at Minden and Gardner-

[27] Incidentally, it should be noted that this change in the adjustments of seasonally preferred feeds has also resulted in considerable unjustifiable complaint against the administration of the national forests. The areas within forest boundaries furnish only a certain quantity of feed. There is no doubt that under the management of forest officials the grazing capacity of these areas has increased. It is no fault of the official if more feed is desired than can be furnished by that area. His duty requires him to prevent any injury of the area under his control.

ville, and near Wellington, Yerrington, and Wabuska. Small farming areas are found in the Virgin and Moapa Valleys, in Clark County, about Bunkerville, Mesquite, Overton, and St. Thomas, and in Lincoln County, a few around Panaca.

It is strikingly noticeable that real farms are not found in the Humboldt Valley, except around Lovelocks, though the Humboldt River is the major source of irrigation water supply in the State, as shown by the map of the water resources. This map indicates plainly that there is more irrigable land north of the railroad, between Winnemucca and Wells and north to the State boundary, than in all the remainder of the State. Almost none of it, however, is used by crop farmers; it is included in stock ranches.

THE MISCELLANEOUS CLASS

So far as numbers go, even if proper allowance be made for the exaggeration in this category, at least half the landowners in Nevada (not including owners of town property) are in the miscellaneous class.

The area held is comparatively large (three times that classified as in crop farms), and the average area owned by one man (over half a section) is misleading. Familiarity with the actual records warrants the statement that probably three-fourths of the owners listed here owned 160 acres or less.

The facts that 14 of them leased additional railroad land (average amount over 3,000 acres) and that 8 of them held permits to graze cattle and sheep in the forests indicate that some range stockmen were classified in this group because of insufficient or inaccurate data. Several large holdings that were probably leased to stockmen, but for which complete data were not obtained, were intentionally included.

The members of this miscellaneous group consist largely of such holders as the following: (1) Homesteaders who got title to their lands but abandoned them; (2) men or banks that have loaned money on small pieces of land, which they were compelled to take over; (3) all patented mining property, mill sites, etc.; (4) all land held by nonresident owners who still pay taxes but do not lease the land; (5) all those whose lands were shown on the assessors' plats but were listed under other names in their reports; and (6) any one for whom no definite data were obtained. Those not in the assessors' reports were rather numerous. The list probably arises from the fact that changes on the rolls due to transfer of ownership were not kept up to date on the plats. The error involved is of relatively little importance and would not change percentages above the tenths place.

Table 4 summarizes relationships that have already been presented. The figures demonstrate that about one-sixth of the landowners of the State use for the production of range livestock (1) probably three-fourths of the owned land, including over half of the irrigated land, (2) practically all of the railroad-grant land, (3) over 95 per cent of all the forest ranges, and (4) at least three-fourths of the usable area of the public domain, along with (5) a large part of the million acres of the land owned by the members of the miscellaneous group. The overwhelming dominance of this

industry over all others using the land surface of the State is shown statistically in the table and is graphically pictured on the land-tenure map. It is believed that this represents about the only feasible use for by far the greater part of the land area of the State, but that marked improvements in its organization are possible.

TABLE 4.—*Summary of data concerning land tenure and utilization in Nevada, 1926*

[For geographic distribution of holdings and nature of use see pocket map No. 1]

Type of use	Nature of the control exercised							
	Landowners		Land lessees		Holders of permits in national forests for—			
					Cattle		Sheep	
	Owners [1]	Area owned [2]	Lessees [3]	Area leased [2]	Permittees [4]	Animals permitted	Permittees [4]	Animals permitted
	Number	*Acres*	*Number*	*Acres*	*Number*	*Number*	*Number*	*Number*
STOCK RANCHERS—ALL KINDS								
Producers of—								
Cattle	572	1,289,966	48	668,170	237	46,950	2	720
Sheep	210	507,581	31	1,075,430	7	140	86	300,985
Cattle and sheep	141	1,197,860	24	1,467,780	42	13,598	49	201,760
All stock ranches	923	2,995,407	103	3,211,380	286	60,688	137	503,465
Per cent of grand total	16.0	67.8	74.1	98.3	69.3	94.5	94.5	98.7
FARMERS—ALL KINDS								
Farmers with range stock	429	141,662	14	8,440	42	1,067	4	780
Farmers only	1,121	214,237	8	3,580			1	15
All farms	1,550	355,899	22	12,020	42	1,067	5	795
Per cent of grand total	27.0	8.1	15.8	0.4	10.2	1.7	3.4	0.2
MISCELLANEOUS								
Miscellaneous of all kinds	3,275	1,065,533	14	42,260	8	1,239	1	1,512
Per cent of grand total	57.0	24.1	10.1	1.3	1.9	1.9	0.7	0.3
Permittees with incomplete land data [5]					77	1,230	2	4,306
Grand total	5,748	4,416,839	139	3,265,660	[5] 413	[5] 64,224	[5] 145	[5] 510,078

[1] Number of individuals or firms owning land, as shown on assessors' plats.
[2] Estimated acreage of owned or leased land determined by assuming that each surveyed section contains 640 acres.
[3] Number of same individuals or firms who leased railroad lands.
[4] Number of same individuals or firms who held grazing permits in the national forests.
[5] See explanation on following pages.

Besides the landowners shown in Table 4 there were 79 other permittees for whom no record of owned land could be found on any of the available records. (See footnote on p. 23.) Of these permittees 19 were Indians. Many of the Indians of Nevada have had land allotted to them, but since the patent has not been issued the land is not assessed for taxation and is, therefore, not on the assessors' records. These 19 Indians held permits for 158 cattle and horses; probably most of the animals were horses. Four of them together held permits for 124 of the 158 animals. The numbers permitted to each of these owners were such that they would fall in the "farmers

with range stock" class if the records had shown that they owned any land. The others average less than three head per permit.

Of the 79 permittees, 37 probably live in town, as they are taxed for town property and do not own land outside of town. Of these, 2 hold permits for 33 and 19 head of cattle or horses, respectively, and the other 35 average exactly 5 head per permit. The two mentioned probably rented some farm land and should fall in the class of "farmers with range stock."

There were 23 other permittees in this group, all but 6 of whom held some taxable property as shown by the tax reports. The assessors' reports show the nature and value of the property but do not show the acreage nor location of real estate. The forest records show the numbers of animals permitted. Judging from such data alone, there are 5 permittees of the "cattleman" class, having permits for 456 head, and 16 permittees that would be classed with the "farmers with range stock," having permits for 389 head, an average of 24 head each. One has a farm flock of 28 sheep also. There are two other permittees having permits for sheep. One of these is a bank having an annual permit for 3,028 head. These sheep were either some taken on a mortgage, or the bank got the permit for some borrower who controlled land. The other is a town resident with a permit for 1,250 head that are probably run on rented land when outside the forest.

The table as it stands shows all the owned land except allotted Indian lands. The classification is explained and its limitation recognized. The permits just noted indicate some possible corrections. If it be assumed that the estimates made above show a correct classification and that the land is already included in the black or red area on the map, both of which are known to be exaggerated, the indicated changes of the table should be an increase in the number of permittees and permitted stock, as follows:

To the producers of cattle class add 5 permittees and 456 cattle; to the producers of sheep add 2 permittees and 4,278 sheep; to the farmers with range stock add 4 Indians, 2 townspeople, and 16 others, and 565 head of cattle or horses and 28 sheep; and add 50 permittees and 209 cattle or horses to the miscellaneous group.

These changes if warranted (1) would not change the land area at all; (2) would increase the total number of cattlemen to 577, sheepmen to 212, and total stockmen to 930; would increase the number of farmers with range stock to 451 and farmers of all kinds to 1,572; would raise the number of miscellaneous owners to 3,325 and the grand total of all operators or owners to 5,827; and (3) increase the numbers of permitted stock by 1,230 cattle or horses and 4,306 sheep.

IMPORTANT STEPS IN THE DEVELOPMENT OF THE LIVESTOCK INDUSTRY

Certain outstanding conditions in the range-livestock industry in Nevada are so directly traceable to previous events that a clear understanding of these conditions is best obtained by reference to what led up to them. A mere chronological synopsis of principal events will be given, with emphasis on those that are more important.

The first steps in the occupation and development of what is now Nevada have already been described and the relationships of other developments to mining have been pointed out (p. 19). The peculiar environment and the new kind of industry resulted in a type of organization that was not thought out in advance. Everyone was directly interested in mining even if he might be for the moment cooking in a "hotel" or driving a "bull team." Consequently everything was thought of as subservient to mining, and all customs—there were no laws—as to land ownership, use of timber and water, mineral discovery and development, were made to fit the principal business and the region. The commanding officer of the American forces (Mason) at the close of the Mexican War is quoted as saying to the miners:

> The Mexican law is abrogated. This is public land and the gold is the property of the United States; all of you are trespassers.[28] But the Government is benefited by your getting out the gold. I do not intend to interfere.

Later, when some kind of official government was considered necessary, they placidly adopted the laws of certain eastern States and the common law principles and went on following their customs. The law passed by Congress in 1866 [29] merely made legal the local customs and laws of the country, without defining any of them. During much of this time the existing laws were being unwittingly and thoughtlessly violated.

Meanwhile the enormous wealth of the Comstock lode had been discovered (1859) and was being exploited; Virginia City had become the center of population of the region, and the Territory of Nevada had been organized (1862). The Civil War had been fought, and Nevada had become a State.

The mining law of 1866 established the principle of the right to put water to beneficial use outside its natural channels without returning it undiminished in quantity, as required by riparian law. It also established the priority-of-use right, which is so important for irrigation. This law was primarily written to settle the mining troubles and to give properties worth millions of dollars a legal status. Much of the California mining was placer mining and required water to wash out the gold. So the customs and their change to laws took care of mining water rights and included the use of water for agriculture as well. Waters used for mining and agricultural purposes were recognized as under the jurisdiction of the State. Later expansions of the meaning of the phraseology have included stock water along with waters used for mining and agriculture. It is now possible under the existing State water laws for an applicant to have allotted to his use by the State engineer the water—wells, spring, or seeps—found on public lands, without the need of owning the land upon which it arises. It is also desirable for the owner of land having such wells or springs upon it to have the water officially allotted; and it must be kept in beneficial use in order for him to retain the allotment. This law is made the basis of a later law which is discussed elsewhere (p. 35).

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[28] Referring to the United States law of 1807 claiming all mineral found in the earth for the Federal Government.

[29] Sec. 2339 R. S.

In 1880 another legal step was taken that is probably more directly responsible for the existing organization and status of the livestock business of this State than any other one thing which has happened. When admitted to the Union, Nevada received a grant of land for its public school system. Like other western States, it was given sections 16 and 36 of each township or lieu selections for all such land as was already taken in these two sections. In 1880 its Representatives went to Congress with the plea that the State had been unable to dispose of more than a few thousand acres of these lands (229,000 acres to 1880) and was unable to get any income for the schools out of the lands then held. It was proposed that Congress take back the lands remaining unsold (over 3,000,000 acres) and give the State 2,000,000 acres, which State officials were to be allowed to select. Congress agreed, and the exchange was made. In 1885 the State remodeled the State land laws and provided for the selection and sale of these lands.

It was this exchange that made possible the purchase of large holdings that cover all the hay land, irrigation water, and most of the stock water found in the region, and thus dominate the use of much larger areas of contiguous and associated public range lands. The State land laws were so drawn as seemingly to prevent such a concentration of control, but the interpretation made of them allowed it, and the lands were sold.

This condition has always been more characteristic of the northeastern corner of the State than of any other part, probably for physiographic reasons. It prevails to some extent elsewhere but is now showing signs of disappearing in places, even in Elko County, where it is probably best exemplified. It still dominates the industry and delays the development of the State, as it has done for probably 25 years.

Easy money obtained from mining ventures may have caused some of these large businesses to develop, but it is more likely that they simply grew under the direction of capable, hard-working, and ambitious organizers. Most of them are the creations of individuals who later organized and incorporated into stock companies for business advantages. The land laws permitted an applicant for State lands to pay 20 per cent of the purchase price ($1.25 per acre)[30] or 25 cents per acre down, and the remainder in a period of years,[31] with interest at 6 per cent. Under this arrangement the applicant could get the use of the land for a down payment of 25 cents per acre and 6 cents per acre per year (plus taxes) thereafter.

The rate at which the lands were taken is an indication of the generalization in the preceding paragraph. Table 5 shows, for some of the larger purchasers, the amounts of land applied for, the period over which the applications were made, and the dates at which the patents were issued.

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[30] Within the limits of the railroad land grant the price was $2.50 per acre.

[31] The period first established was 10 years. It has been lengthened at various times and now stands at 50 years. The contract of purchase therefore amounts to a 50-year lease at 6½ cents per acre per year, or double that amount on the $2.50 land. In some instances fees that were required raised the price considerably. These prices would be low rentals for irrigated or subirrigated lands, but they are very high for the lands not supplied with water. The railroad-grant lands (over 3,000,000 acres) are to-day rented at an average price of 2½ cents per acre per year; they return only about half their annual cost (taxes) to the railroad.

TABLE 5.—*Data showing the periods during which some of the larger landowners were purchasing their State land holdings*

Applicants	Year of earliest application	Year of latest application	Year in which patents were issued	Separate holdings purchased	Total area bought
Number				*Number*	*Acres*
1	1867	1910	1917–1921	53	12, 303
1	1872	1909	1916	63	25, 330
1	1872	1904	1909–1913	229	128, 950
1	1873	1921	1922	204	39, 369
1	1882	1897	1917	123	67, 826
1	1886	1926	1919	67	23, 950
6				739	297, 728

Fifteen or twenty years ago the practice of incorporating these larger properties was begun. This made necessary the completion of the purchases of State lands, in order that they might be used, along with improvements, water rights, livestock, etc., as the contribution of the owners to the capital stock of the companies to be incorporated. Securities of such companies were sold on the market for a number of these companies, and the ownership of many of them now largely rests in investors entirely out of contact with the business itself or the interests of the State as a social unit. The securities represent investments that are good or bad only as they pay or do not pay dividends.

The owners of the securities of a number of these incorporated companies are the heirs of undivided estates who have taken this means of dividing ownership without dividing the property. Often these heirs do not wish to be directly associated with running a stock ranch. Few of them live on the property, many live in near-by towns, some of them have gone to California. They have no interest in the property except as a means of earning incomes—a function several of the ranches have failed to perform for some time past.

The burden of taxation in Nevada falls heaviest upon the agricultural lands. The largest taxpayers are the railroads, which furnish, roughly, about 40 per cent of the taxes. Second in importance among taxpayers is the livestock industry, though the gross income from mining is probably two to two and one-half times that from the livestock business; and the land, which carries the heaviest burden, belongs mostly to the large livestock operators. Naturally they are now anxious to be relieved of such burdens, and the properties of many of these companies are for sale.[32]

These owners wish to sell all their property as a unit, not subdivide and sell in pieces. Many of the pieces that are important parts of the whole would have little value if offered separately; but possible buyers of such large properties are not numerous, and the outstanding securities which are liens upon the lands in many cases prevent

[32] The report of the Nevada State Equalization Board (p. 23) shows that the livestock interests of the State paid about 18 per cent of all taxes paid in 1926. Of this total, about 11 per cent was assessed upon their lands and 7 per cent upon their livestock and other personal property, not including automobiles. A little over 4 per cent of the total taxes assessed were paid by the railroads upon their grant lands. The rentals for such of these lands as stockmen leased amounted to half of the taxes paid. Hence stockmen actually contributed approximately 20 per cent of all taxes paid that year. About the same proportion has been paid for several years past.

sales that might otherwise be made. It was this condition that led Dan Casement,[33] who was appointed by the Secretary of Agriculture to review grazing fees in national forests, to say: "Contact with stockmen in Nevada leaves one with the impression that ranch and range lands in the State are regarded as very burdensome, if not actually undesirable, possessions."

Efforts to maintain the domination of large businesses and to keep up the morale of those who are weakening give rise to the generalizations heard there: That Nevada does not need or want more people and ranches; that what it needs is fewer and bigger ranches; that certain parts of the State (which have been cattle ranches for half a century) could be much more profitably and effectively used as winter ranges for sheep.

Yet the one outstanding irritation that has beset the cattlemen for years has arisen from nomadic sheep, and the laws that have been passed in attempts to control the sheep number more than all other range laws together. It has already been shown that winter snow and existing lack of law controlling grazing on the public domain, when taken together, give the sheepmen advantages that have so far not been met by cattlemen.

Laws to prevent sheep from other States coming into Nevada were repealed because some Nevada sheep go into other States for summer feed. A law that required all stockmen using Nevada ranges to own Nevada land was declared unconstitutional, though it lasted long enough for one speculator to lose $18,000 to $20,000 of first payments on all the available State lands. He expected to sell such lands at much higher prices to Utah and other extra-Nevada sheepmen who wished to graze Nevada lands in the winter. The land ultimately reverted to the State and was resold.

The national forests of Nevada were established at the request of resident stockmen, who keenly felt the need for a means of keeping nomadic sheep off summer ranges. Some of the stockmen who now can not qualify for permits in national forests are urging changes in the administration of those areas for any reason that seems plausible, in the hope that under a new arrangement they might get something better than what they have now.

The latest legislative attempt to control the nomadic sheepman is what is known as the 3-mile limit law, which restricts the use of allotted water and associated forage as a regulatory act under the police power of the State government (p. 40).

In the evolution of the range industry of Nevada certain fixed opinions have developed among stockmen that have become the accepted, almost authoritative, rules governing the operator. When men began to use the grazing lands in the Humboldt River Valley they raised cattle. In that region it is necessary to feed cattle one or two months in the winter. The only feed available was native-grass hay, but there were many thousands of acres of flooded valley lands covered with giant ryegrass ready to be made into hay. Control of the winter feed meant control of the range, and for years cattlemen have determined the number of stock their ranges would carry by the number of tons of hay they could cut for winter feed.

[33] CASEMENT, D. [THE RACHFORD REPORT.] Letter from Dan Casement to W. M Jardine, Secretary of Agriculture. 21 p. 1926. [Mimeographed.]

It was this set of conditions and the reasoning that grew out of it that brought about the exchange of school lands and the concentrated ownership of hay lands.

The subirrigated lands produced excellent spring pastures, originally in native grasses, but later, to some extent, seeded with the common cultivated pasture grasses. Such pastures, associated with hay and outside range, made possible the grass finishing of 3 and 4 year old steers that found a profitable market in California, where such beef animals could undersell a better but more expensive product originating east of the Rocky Mountains.

Operators who were fortunate enough to be fully equipped for this type of beef-cattle raising were prosperous, and their methods were assumed to be those that should be applied by all cattle raisers in the State. This type of beef production still is profitable for the man with the properly organized ranch business, but other systems of cattle raising are probably better suited to present conditions on many ranches. Yet many cattlemen are strongly convinced of the superiority of the established system.

Raising sheep began very shortly after cattle production began. The sheep have always been handled in bands and have always competed more or less with the cattle for range forage. Under such competitive conditions on an open, free range, sheep have some advantages over cattle, and this is especially true where snow is associated with browse feed in the winter. The desert ranges, as they were called, were an invitation to sheep from other States, and they encroached more and more upon the cattle range. The first important effects of extra-Nevada sheep were felt in the summer ranges of the mountains, and accordingly the national forests were established. Since then their crowding on the winter ranges has been increasingly serious.

The coming of the national forests and the development of a more complete utilization of the available irrigation water, which was accomplished by small operators who do most of their own work and live on and farm their irrigated lands, changed the relationship of the different sources of feed in a large part of the State. These small operators developed water and were given permits in the adjacent forests. The hay they raised, mainly alfalfa, gave larger yields than the grass hay, and their use of their irrigation waters was more economical and effective.

Nowadays the industry finds its expansion limited not by winter feed but by summer feed. The steady reduction in range feed on the public domain is also becoming important, though many of the stockmen will not acknowledge it. Many thousands of acres that were formerly grass patches in the sagebrush area are now covered with sagebrush itself and with more or less useless annuals, and the winter-fat and little-sage areas are badly grazed down. Most of the scattered bunch grasses are grazed so closely that they are not producing seeds. Several valuable native species of Poa, relatives of Kentucky bluegrass, and some of the best feed grasses formerly reported from these ranges were absent in 1927, when the writer was looking for them. But all the earlier publications dealing with Nevada range forage plants tell about them and name the species.

In summarizing these tendencies it may be said that the development of the water-utilization laws was beneficial; that the exchange

of the school lands and their sale in large bodies made for the rapid development of a thinly populated area up to the limit of that system of organization; that the control of the national forests came in time to save most of the best summer feed and has since brought about its recovery, at least to a degree; that the opportunities and encouragement afforded small stockmen have brought about the development and better use of much of the natural water; and that, along with other factors, this development has exerted some pressure tending to bring about the subdivision of the larger ranches.

The crowding and overgrazing of ranges by nomadic sheep have done no one except the nomad any good and have done the ranges outside of protected areas enormous harm. These nomadic sheep are in a fair way to displace some of the year-long cattle ranchers who are and wish to continue to be permanent residents.

Nevada needs two things: (1) Better use of some of its irrigated lands in smaller parcels and by a larger number of people and (2) fenced stock ranches used by individuals or small groups who will develop the stock waters and protect and improve the range forage. Such improvements can be made and would benefit the State as a whole.

THE LEGAL STATUS OF THE PUBLIC DOMAIN

All of the data presented have demonstrated the limitations placed upon the economic advancement of Nevada by the lack of legislation to make possible the better utilization of the public domain.

All of Nevada, along with much more of the land area of the Union, was originally the property of the Nation, to be disposed of by Congress as it saw fit. The various States carved out of this Federal property and admitted to the Union by Congress agree, in their constitutions, that the lands of the State should be brought under the complete jurisdiction of the State government only after they had ceased to be the property of the Federal Government.

The enabling act of Nevada contained the following agreements, which are written into the State constitution. The people of Nevada agreed that—

(1) They will forever disclaim all right and title to the unappropriated public lands lying within said territory;

(2) That the same shall be and remain at the sole and entire disposal of the United States; and that

(3) No taxes shall be imposed by said State on lands or property therein, belonging to, or which may hereafter be purchased by the United States.

From this it appears that political jurisdiction and exclusive power over these lands was not retained by the United States. What was retained were ordinary property rights, with power of disposal, and freedom from taxation. In respect to these lands, the Federal Government is in the status of a private owner, with special privilege as to taxation, until Congress so acts as to establish some other status.

The admission of the State of Nevada into the Union made it amenable to the Federal Constitution; hence, powers granted by that document to the Federal Government automatically applied to Nevada. Under the Federal Constitution, Congress is authorized to dispose of the public lands.

This limited jurisdiction of the Federal Government over public lands automatically leaves to the State all other powers, except as it is limited by the State and Federal Constitutions and the acts of Congress.

Congress has all along had the authority to act in the disposal of public lands. It has acted with respect to (1) national forests, (2) national parks and monuments, (3) mineral deposits of certain kinds and the disposal of them, (4) Indian lands, and (5) various other lands. But it has never acted in respect to use of the public domain except indirectly.[34] Certain rulings of the Secretary of the Interior have been supported, and in 1885 Congress passed a law prohibiting the inclosure of lands of the public domain with a fence. Grazing of livestock upon the public domain has always been allowed and declared by the courts not to be trespass.[35]

Thus arises the existing condition of the public domain. It is an open "commons" upon which the livestock of any citizen may graze without charge. No one has legal authority to appropriate a part of it exclusively to individual use, to inclose any part of it with a fence, or directly to prevent anyone from using it.

Since many of the plants growing naturally upon most of this public domain have some forage value, and such forage is free for the taking to him who can get it, there has been more or less competition for it since white men have occupied the region.[36] This "first come, first served" principle, when applied to free feed, usually results in friction or something worse, and then the police power of the State is invoked to maintain the peace. The State has always been sustained by the United States Supreme Court in the exercise of this power so long as there is no violation of the Federal Constitution. An act once passed by either State or Federal Government becomes the law until repealed; and any property rights obtained under it, while it is in force, will be defended by the courts, whatever action may be taken later.

Early in the development of the new country the constant dissension between stockmen and other settlers or between owners of one kind of livestock and owners of another kind resulted in what passed for legislative action. In California in 1857 a law was passed making the herding of sheep on "land or the possessory claim" of another than the owner a trespass and finable in two counties. This was later extended to more counties and finally to the State. Idaho passed a "2-mile limit" law[37] which was sustained by the State courts[38] and finally by the United States Supreme Court in 1906.[39] This law prohibits any person owning or having charge of sheep to herd the same, or permit them to be herded, on the land or possessory claims of other persons or to herd the same or permit them

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[34] This statement refers to the management of these lands while still the property of the Federal Government. Very definite laws regulating the transfer of title to these lands have been on the statute books since the Nation was established.

[35] Buford *v.* Houtz, 133 U. S. 320.

[36] The writer once asked the chief of one of the Pueblo tribes of New Mexico why the grazing lands of their reservation did not show overstocking. His reply was that they had known for many years about what the range would carry and the tribe had maintained that limit. Most white men who have control do the same thing. Without control of prescribed areas, such regulatory measures can not be applied. The recognition of the necessity by the Indians had probably resulted in a tribal custom that is now obeyed without question.

[37] Sec. 1210, 1211 R. S.

[38] Walker et al. *v.* Bacon, 81 Pac. 155.

[39] Bacon *v.* Walker, 204 U. S. 311.

to graze within 2 miles of the dwelling house of the owner or owners of such possessory claim.

In 1925, Nevada passed its "3-mile limit" law, which has already been mentioned; some of the consequences are considered at some length in the next section (p. 40). The law has been declared constitutional by the State Supreme Court, but has never been before the United States Supreme Court.[40]

As will be seen, the effect of these laws is to restrain certain individuals from the use of the public domain in specified areas—a power delegated to Congress only, but allowed by the courts because Congress has not acted and the peace must be maintained even at the expense of "even-handed justice" or "ideal fairness."

One further step in this process of getting individual control of the public domain for grazing purposes was taken in 1929 by the State of Colorado. The State legislature passed a law which assumes that the custom of grazing livestock on the public domain is an established custom carrying with it possessory rights that have the status of private property, and that these possessory rights are therefore subject to the laws and court decisions of Colorado that relate to them. Then, acting under its police power and to prevent conflicts between individuals, the legislature declared that—

> the question as to the kind of livestock, whether cattle or sheep, that shall have the preferred or better right to graze upon any particular portion of the public domain within this State shall, from and after the passage of this act, be determined according to the use made thereof during the last grazing season prior to the passage of this act, whether such use was as a cattle or sheep range and whether the same was used as a spring, summer, fall, winter, or other kind of range.[41]

This law places the responsibility of determining the nature of the range use for any area upon the district court when a case is brought before it and sets forth certain methods of procedure and principles of action for the guidance of the court. It also commits the State government to a policy of conservation of the forage resources of the public domain and the prevention of overstocking and erosion. It authorizes the court to determine the number of animals that a range may carry. This law has been declared to be constitutional by the State supreme court.

Two other acts of Congress bear on this subject. At the request of the people living in a few contiguous townships in Montana, the Secretary of the Interior was given authority to lease the public domain within those townships. Congress has authorized the withdrawal of many thousands of acres of public domain from entry, in the Owens Lake region of California, to protect the water supply of Los Angeles. But grazing is permitted upon these lands under rules and regulations of the Secretary of the Interior.

Thus, various indirect legal methods have been used to get individual control of the range lands of the public domain. The fencing law passed in 1885 was intended primarily to prevent stockmen from establishing possessory rights to large areas of public domain under State laws that recognize such rights as may arise from

[40] Until the U. S. Supreme Court is called upon to decide the constitutionality of this law or unless Congress shall take adverse action, the State law will continue in force. Previous action of the U. S. Supreme Court has established precedents which appear favorable to a confirmation of the constitutionality of this law.

[41] Colo. Sess. Laws, 1929, p. 443.

undisturbed possession and use of property for a period of years. Before that law was passed hundreds of thousands of acres of the public domain in the Great Plains had been fenced and homesteaders had been driven off.

While these events were taking place the desired end was being approached from an entirely different angle—that is, through the control of the very limited supply of water. It has been shown how Nevada stockmen used the control of irrigable land and irrigation water to control winter feed, which was the key to the control of the large acres of the arid grazing land that constitute the public domain in that State. The way this method was worked out and applied has been discussed (p. 33), and the limits of its effectiveness in Nevada have been stated. The net result has been to build up the water laws of the State as they exist to-day.

The feature of these laws that needs discussion here is the extension of the idea of the ownership of the waters of the State to the stock water, and the law authorizing the State engineer to allot all such water whether on private lands or public domain. Acting under the provisions of this law, the engineer has allotted many such sources of stock-water supply over the State. (Fig. 4.)

In April, 1925, the State legislature passed a law which prohibits any person from watering

> on two or more separate days, during any season, more than 50 head of livestock at the watering place at which another shall have a subsisting right to water more than 50 head of livestock, or within 3 miles of such place, with intent to graze the livestock so watered on the portion of the public range readily accessible to livestock watering at the watering place of such other person.[42]

This law also forbids the issuance of water allotments to waters from the same or different sources, the use of which will impair the use of the surrounding public range if that is already fully occupied by livestock watering at places already allotted. This law has been declared constitutional by the State supreme court,[43] but has not yet been before the United States Supreme Court.

Just what effects this law will have is not yet evident. It patently attempts to restrict the use of the public grazing lands to the stock belonging to men having "a subsisting water right," which will cover other vested rights or allotments more recently made. It will give incentive to present owners of watering places to develop more and thus bring about the long-delayed development of the underground sources of water in the State. It remains to be seen whether or not, in the meaning of this law (1) snow lying on the ground is to be considered a "watering place" or (2) allowing sheep to eat snow is a method of "watering" them. If a court of competent jurisdiction decides these questions in the negative, nomadic sheep that use snow only may graze anywhere on the public domain that snow and feed are found together.

THE RECORDED RANGE CLAIMS

These two limitations upon the use of range forage and stock waters have produced another result that was not anticipated. This

[42] Nev. Stat. 1925, p. 348.
[43] In re Calvo, 253 Pac. 671.

is in consequence of the action of the State engineer, whose business it is to make water allotments. The new law places considerable responsibility upon him, since it prohibits the allotment of stock waters on ranges where operators having subsisting water rights run live stock on the surrounding range " in sufficient numbers to utilize substantially all that portion of the public range readily available to livestock watering at that place "—that is, the allotted waters. This makes it necessary for the State engineer to have accurate knowledge of the ranges used by the men having the water rights. He has a record of all water allotments made and of some of the vested water rights, but at the time the law was passed he did not know the limits of the ranges as claimed by stockmen.

The engineer made this clear to the stockmen and told them that if they would furnish him with maps showing the extent of their range claims he would keep the information on maps filed in his office. He promised the stockmen that whenever an application was made for an allotment of water he would notify the man whose business might be affected by such an allotment, so that such an operator might enter a protest against the granting of the application. The action taken would then rest on the evidence as to whether the range was already " substantially utilized."

The result was the preparation of maps which are on file in the engineer's office at the State capitol. Through his courtesy and the assistance of one of the district extension agents [44] of the State agricultural extension service, a large-scale copy of a State map on which these individual range claims had been assembled was made available to the writer.

On this map as a base the owned and leased lands controlled by the claimants were entered and the claims numbered so that they could be identified. This " range-claims " map is in the pocket at the back of the bulletin. (Pocket map No. 2.) It presents a picture of the actual conditions that result from lack of some system of control in an open-range country.[45]

No sufficient description of the resulting situation can be put into words, though several facts may be noted. The first impression made by the map is the amazing jumble of overlapping claims of all sizes and shapes. When it is remembered that this map records the claims from not over 20 per cent of the stockmen in the State, the complexity of the situation is appreciated.

The claims vary in size from the small claim of a half to a whole township with an associated area of compact, consistently located, legally controlled land, inside the claim, to the enormous claims of certain companies that have nothing but some stock-water allotments, and an occasional 40-acre piece of land. Some of the claims registered have no associated owned land but merely certain "possessory-rights," as stated by the county assessor.

There is a principle of action that arises out of our method of making laws under the common-law principle—namely, that so long as there is no law prohibiting it, one may do anything that is to his own advantage. If some practice or method of action not formally

[44] C. R. Townsend.

[45] To include the areas used by these claimants in national forests was found impracticable because of the extreme complexity of the map.

controlled by law but resulting in good to those using it becomes an established custom and rights are developed thereby, these rights have the status of possessory rights, and the courts will defend them. So long as the individuals who might be competitors in the field get along together without dissension and do not arouse the public, the practices may continue. Once the matter is aired and laws are made, the practice must follow the law, but the possessory rights usually get some legal recognition.

This general principle of action has long been well understood by the stockmen in Nevada and has been in practice for many years (*1*). These stockmen have become so thoroughly habituated to using indefinitely defined large areas of pasture land to which they have and can get no statutory rights that they are watching for opportunities to establish possessory rights, especially if they cost nothing, in the expectation that when statutory rights are established, equities in the form of possessory rights, adherence to custom, priority of utilization, etc., will receive due consideration in the new adjustment.

Their position is well taken, since it gives present advantage and profit, and the habit of the courts is officially to recognize all such property rights in so far as they can. This is particularly true when the law-making power that has authority to consider the subject and establish statutory principles does not exercise its function.

That men of business acumen and common sense have taken advantage of such a situation is plainly evident from the map. Some of the claims are conservative and clearly represent an effort to put on the map no more than the area that the operator can prove he has "substantially utilized" for years. Others are as patently an effort to develop a claim to as large an area as possible. Ranges recorded a second time by the same parties and considerably enlarged illustrate this expansive tendency.

The following are some brief generalizations concerning these claims that have been worked out from the data available. They point out the high lights of the picture.

The law was passed in 1925. The State supreme court declared it constitutional in February, 1927. By October of 1929, 199 claims had been recorded.

Counting out duplications and claimants having no owned or leased land that could be found, 164 claimants are represented.

Of these, 149 are the same parties enumerated as "range stockmen" in the tables showing tenure and use of lands. (P. 24 and Table 4.)

The gross area (estimated) of all the separate claims is about 65,056,000 acres.

The area of duplications and overlaps is approximately 20,338,000 acres.

The net area covered by all reported claims, eliminating duplications, is approximately 44,718,000 acres, or 63 per cent of the total area of the State.

The area owned or leased by these claimants is approximately 2,791,000 acres, or about 6 per cent of the net area claimed.

Of the 149 range stockmen mentioned, 91 raise cattle only, 28 raise sheep, and 30 produce both cattle and sheep.

Of these 91 cattle raisers, 40 had permits to run 15,013 cattle and a few sheep on the forests in 1926.[46]

Of the 28 sheep raisers, 8 had permits to run 72,297 sheep in the forests in 1926.[46]

Of the 30 producers of both cattle and sheep, 13 held permits to run 10,725 head of cattle and 12 held permits to run 111,602 sheep in the national forests in 1926.[47]

Table 6 gives the details of these relationships and should be compared with Table 4 which shows land tenure and use for the whole State (p. 30).

The landholdings and permits of the few claimants found in any of the use classes other than range stockmen are shown in Table 6. These probably also show some of the inaccuracies in the data which were not eliminated by the methods used.

TABLE 6.—*Summary of data concerning recorded range claims, Nevada, 1929*

[For geographic distribution of claims see pocket map No. 2]

STOCK RANCHERS—ALL KINDS

Type of use	Nature of control upon which claims rest									
	Land owners			Land lessees			Holders of permits in national forests for—			
							Cattle		Sheep	
	Claimants [a]	Claims	Area owned [b]	Lessees [c]	Separate leases	Area leased [b]	Permittees [d]	Animals permitted	Permittees [d]	Animals permitted
Producers of—	*Number*	*Number*	*Acres*	*Number*	*Number*	*Acres*	*Number*	*Number*	*Number*	*Number*
Cattle	91	102	375,568	11	20	181,410	40	15,013	2	720
Sheep	28	31	157,470	5	14	482,610	------	------	8	72,297
Sheep and cattle	30	34	672,960	5	36	1,014,120	13	10,725	12	111,602
Total	149	167	1,205,998	21	70	1,578,140	53	25,738	22	184,619
Percentage of grand total	90.8	------	99.4	100	------	100	96.4	99.6	100	100
FARMERS—ALL KINDS										
Farms with range stock	9	9	4,397	------	------	------	2	100	------	------
Percentage of grand total	5.5	------	0.4	------	------	------	3.6	0.4	------	------
MISCELLANEOUS—ALL KINDS										
All kinds	6	7	2,160	------	------	------	------	------	------	------
Percentage of grand total	3.7	------	0.2	------	------	------	------	------	------	------
Grand total	164	183	1,212,555	21	70	1,578,140	55	25,838	22	184,619

[a] Number of individuals or firms owning land, as shown in Table 4, who have recorded range claims.
[b] Estimated acreage of owned or leased land, calculated on the assumption that each surveyed section contains 640 acres. Such figures are usually about 1 per cent over assessed acreage.
[c] Number of same individuals or firms who leased railroad lands.
[d] Number of same individuals or firms who held grazing permits in the national forests.

[46] There are usually only a few changes in the forests each year.
[47] Some of the men holding permits for cattle also obtained sheep permits.

SUMMARY AND CONCLUSIONS

This study was undertaken to ascertain the conditions peculiar to different parts of Nevada and to the State as a whole that would have to be taken into account in any attempted solution of the range problem. Nevada was chosen because it has more public domain and a greater proportion of its area in public domain than any other State and because it is more dependent economically on the public domain than is any other State.

At various times a number of methods of disposing of the public domain have been proposed. Four of these that have received serious consideration are listed here without reviewing their advantages and disadvantages. They are (1) selling the land at a reasonable price, (2) giving the land to the State in which it is located and allowing the State government to dispose of it, (3) leasing the land at a reasonable price, and (4) establishing a system of Federal control over these lands modeled upon the plan of the permit system now in use in the national forests. These proposals have always contained limitations and various safeguards. Sometimes the limitations are stated definitely, and at other times the duty of proper administration is assigned to a responsible authority. Each proposal has been made to cover the whole of the public domain.

One general conclusion is reasonably certain. In the regions where competitive grazing on public lands prevails with little restraint, any one of the various methods that have been proposed for the disposal of the public domain would be more satisfactory than our present habit of letting things drift. Each plan would have advantages in certain regions and disadvantages in others.

Studies made in several of the States indicate that there is no single simple policy that can be applied satisfactorily to the remaining public domain, since under any set of assumptions as to the ultimately desirable, that action which will be acceptable in one State may not be acceptable (and usually is not) in others. Each State has developed a set of laws and customs that differ more or less from those of other States. Stockmen have acquired various degrees of control over the use of the public domain, and this use is correlated in numerous ways not only with that of their own and other private lands, but with State lands, Indian lands, and national forests. Each geographic region imposes different physical limitations upon the business of range stock raising.

Nevada is a rather striking example of these varied regional conditions. Northeastern Nevada has one set of conditions and an established organization now in operation, characterized mainly by large holdings of irrigable land and the ownership of the associated irrigation water rights. Many of these operators are incorporated firms with securities in the hands of scattered nonresident owners who have no close personal interest in the region and its development. The use of the resources held by these stockmen is so important to the State as a whole that the question of how best to utilize the region becomes a separate problem for solution. In east and south-central Nevada another set of conditions is found. Here the amount of irrigable land and irrigation water is so limited that its proper utilization does not constitute a separate problem. In the northwestern part of the State the use is more nearly like that in the

east and south-central parts, but this condition has developed recently, and further adjustments are to be expected. In the southwestern part of the State the use of the land is so dependent upon the feed and the scanty supply of water that permanent occupation by stock of anything but small, scattered areas is not to be expected. The extreme southern part of the State, below 37° latitude, has very little permanent stock water and almost no snow, with very scanty feed, and only a few stock. Sheep rarely go there, and cattle can stay the year through in only a few places.

The study of the physical conditions, the tenure and use of the land and water, the historical and legal factors, and the claims made by stockmen indicate certain generalizations that are considered basic to any conclusions that may be reached. They are:

Most of the tillable land of the State and the associated irrigation waters belong to stockmen and are employed mainly in the production of hay that is requisite for the best utilization of the associated grazing lands.

The public domain in Nevada is all arid grazing land, except the absolute desert, which has no known agricultural use.

All the usable part is now fully occupied and employed as open range by tacit permission of the Federal Government.

Free, open-range grazing leads to (1) nomadism, (2) overstocking, (3) cumulative range deterioration, (4) soil erosion, and (5) final complete destruction of the grazing resources, to say nothing of continual friction among the users. Nomadism tends to disorganize the business of permanent settlers, and eventually to drive them away.

These arid grazing lands are capable of greater or less improvement under better managerial practices than can be applied on open, uncontrolled ranges.

Operation of these lands in separate units under proper restrictions, by individuals, or small groups is the best method known.

Operators can not afford to apply the known practices that bring about improvement unless they can be guaranteed the resulting rewards of their efforts.

The right of any State to exercise police control over citizens on the public domain within the State is recognized by the Supreme Court of the United States.

The right to graze on the public domain has been recognized by the courts and is considered a property right.

This study has shown that active livestock producers in Nevada are warranted, on some or all of the following grounds, in believing that their interests should be carefully considered in any adjustments that may be made: They own the lands and control the irrigation waters that are the keys to the use of practically all the grazing lands, they hold nearly all the grazing preferences in the national forests of their State, they have most of the possessory rights on the public domain, they hold most of the stock-water allotments made under the laws of the State, and they lease nearly all of the usable railroad grant lands. This domination of the grazing resources of the State is the result of years of development and the gradual acquisition of the various rights and privileges mentioned. The existing stockmen have built up and now operate the second largest business in the State, and they pay more taxes than any other industry in the State except the railroads.

An obvious desideratum in carrying out any plan is the sympathetic cooperation of the people concerned. In order that the next step in advance may be taken, the present status of development of the business must be clearly understood and should not be suddenly and drastically modified. So far as possible such modi-

fications as may appear desirable in the public interest should be worked out gradually.

Nevada stockmen are confirmed in the belief that the range lands of by far the greatest part of their State can never be used as anything but *open* ranges. They may be correct; nothing else has ever been tried. But if experience in other States having large areas of arid grazing lands is to be trusted, the best use of such lands is to be had only when they are fenced. Even a system of regulated grazing on unfenced ranges does not give the control necessary for the best practices in handling cattle. This proved true in Texas, where fencing was compelled by State authorities. It has proved true in other range States on all lands that operators could get fenced. Many stockmen so thoroughly believe in the advantages of the practice that in order to be able to fence the lands they use they are ready to lease, buy, or submit to Federal regulations.

Perhaps no body of men are more confirmed in the idea of the desirability of open ranges than the sheepmen of the range States. Yet the chief of the department of animal husbandry, Texas Agricultural College, says that 95 per cent of the 5,500,000 sheep and 2,965,000 Angora goats produced in that State "are grazed 'loose' in wolf-proof pastures in the great permanent ranching area of southwestern Texas." (*5*) By this he means that these animals are in fenced pastures without herders and not handled in bands, as is the common practice. The pastures are usually large, often several square miles in extent, and the fences are wolf proof.

Nobody can now say definitely, and no one will know until it is tried, whether Nevada stockmen would avail themselves of the privilege of fencing if the opportunity were offered.

The stages in development of private range control in the United States have been somewhat as follows: (1) Open, free range; (2) open range limited to operators who control water; (3) open range region subdivided into large areas by drift fences, natural barriers, railroad rights of way, etc.; (4) drift and railroad fences and natural barriers so used as to produce a few large inclosed individual ranches; (5) State, railroad, and other grant lands, in large bodies, fenced; (6) consolidation into private fenced, subdivided holdings, by any method applicable in the region. These steps have been taken slowly or rapidly by stockmen, individually and collectively, and regionally as they have believed they might profit by the change. It is not improbable that such tendencies would emerge in Nevada if and when a greater degree of control of the open range results in range improvement.

If one is to believe the opinions expressed by some of these men to the Stanfield committee and to the present investigators, as reiterated in the official organ of the State Stockgrowers Association and as implied in Dan Casement's report to the Secretary of Agriculture, the attitude of these same men is unsympathetic toward any of the proposals mentioned above (p. 44).

Apparently most Nevada stockmen are not in favor of leasing the public domain, even at the low rates of rental that prevail for railroad grant lands. They say they can not afford even this small charge, since the production of feed on the lands will not warrant it. Hence a leasing system would get little support. A few would

probably purchase some of the public domain if it could be acquired at a reasonable price and on convenient terms of payment, but many claim that the use value of the public domain has already been fully capitalized in the value of associated privately owned land. If the land should be offered to them as an unconditional gift, many would hesitate to accept it on account of the taxes. Most of them, at least those who express themselves most freely, would prefer not to be subjected to any regulatory authority that might impose restrictions for reasons other than those determined by what the operators consider the best interests of their business.

A reasonably definite statement of what they believe to be desirable is rather hard to make. Expressed in general terms, many of them think that legislation is needed which will give them legal right to the privilege they now exercise, and this change from a poorly defined privilege to a legally defensible right would have to come without any large additional cost or they would prefer to have conditions remain as they are.

The Legislature of Nevada has tried several times to pass laws that would stop some of the worst abuses, particularly the encroachments of "tramp" sheep. The courts have done what they could in support of the laws. The latest effort, the 3-mile law, held some promise but has not helped much yet. The law passed by Colorado in 1929 which attempts to restrict the use of certain areas of the public domain of that State to cattle or sheep or for seasonal grazing has not yet been tried sufficiently to warrant passing it in Nevada. The law passed by Montana authorizing leasing in a limited area would not appeal to Nevada stockmen. At best, all such attempts are indirect and only partially effective and are subject to change by any act Congress may pass.

It is reasonably evident that any plan that would attempt to divide the public domain into units having productive capacity equivalent to the original 160-acre homestead and offer to give such units to applicants as homesteads have been given in the past would completely disrupt the business as now organized. These proposed units, composed entirely of public domain, would lack stock water and hay land. The privately owned lands and water rights, although capable of some independent use in most instances, would automatically lose in output because of the loss of the feed now obtained on the associated public domain. The proposed units cut out of public domain would not be economic units. The plan would induce inexperienced men to try the impossible, and at the same time would set up the machinery whereby capable stockmen would be either forced out of business at great loss, or compelled to overcapitalize in order to retain a hold on the economic units they now use.

In any case it seems clear that any plan for leasing or sale that might be developed should be carefully devised so as to give due recognition to existing possessory rights in so far as this is compatible with the public interest, and particularly to protect the numerous small operators who have limited capital and only a few stock but whose possessory rights rest on the same foundation as those of their financially more powerful neighbors. Without such safeguards the business is bound to be more or less disrupted if any major change of policy is made, and some men will profit

at other men's expense. The present organization in any locality represents a delicately balanced condition of the factors of physical productivity, available capital, business judgment, and perseverance that can not be disturbed without very undesirable consequences, both for individuals and society.

The repeal of the homestead laws has been suggested as a desirable policy. Specific recommendation of the repeal of the stock-raising homestead law has been made for several years by the Commissioner of the General Land Office in his annual reports. It is recognized by students of land policies that the general effect of the homestead policy has always been more or less unsatisfactory in several ways, even in those areas to which it was best adapted. That it was never adjusted to conditions in Nevada is shown by the large proportion of the State that is still public domain after nearly 60 years' operation of laws that were designed to transfer the land to private owners. Less than 4,500,000 of the 70,000,000 acres that constitute the land area of the State are owned by private individuals, and of that area about 2,700,000 acres are lands that were given to the State for its school fund. Only about 2½ per cent of the total land area has been transferred to private individuals in that long period through the operation of the homestead laws, though many of the large stockmen would at one time probably have been glad to obtain complete possession of the land they used if it could have been done at a reasonable expense.

In the area loosely referred to as the northeast corner of the State there is a separate problem needing careful attention. Some of the lands of that area and their associated irrigation waters could probably be so used as to produce all the required hay and much besides. Such irrigable lands and their waters, now used more or less inefficiently (Table 3), constitute one of the principal natural resources of the State, and the best interests of the people of the State will be served only when these resources are used at their highest efficiency. This condition is found in only a small part of Nevada and is most evident in the upper Humboldt Valley. This opinion is in agreement with that of Romanzo Adams, who pointed out nearly 14 years ago (*1*) that the inefficient utilization of the best irrigable land and the limited supply of water had led to social conditions less desirable than would exist under a system of more numerous occupiers operating on a smaller scale.

Some of the leading men of the State now recognize that any plan of reorganization, to be of advantage to Nevada as a whole, should anticipate an increase of total production from the area involved without an undue enhancement of costs and should result in a denser population made up of resident operators. This problem of reorganization is a complex and very difficult one that would need to be worked out gradually. To bring about the more efficient utilization of the irrigation water and the irrigable lands would probably involve impounding the water and building better distributing and drainage systems, as well as the subdivision of the land into smaller units, at least part of which would be used to raise other crops than hay and stock feed.

Such a reorganization, if properly financed and managed, would make possible the breaking up of some of the larger properties the

present owners of which are not interested in ranching, and at the same time allow the land and water to be more intensively used. Some of the larger properties are no longer profitable. Others have been subdivided but the subdivision as made has not resulted in the type of reorganization that leads to a more intensive use of the available irrigable land.

In any proposed change in the economic organization of such an area provision should be made for employing as much of the irrigated area as may be required to produce the winter feed complementary to the surrounding range forage, the remainder being made available for other uses.

Such a program should ultimately result in better utilization and conservation of the irrigation water and irrigable land, as well as of the range lands; it should increase the total quantity of crops and livestock and permit the maintenance of a larger resident population of self-supporting owners.

In certain parts of the United States broad national interests have led to the establishment of national forests. The two principal objects of this national policy are (1) timber production and (2) water conservation.[48] Range grazing, recreation, and wild-life preservation in national forests, although desirable, are by-products of the major purposes for which the areas were set aside, and must always be treated as such. It follows that range grazing on national forests is always to be considered as a privilege to the grazer, to be limited or curtailed at any time for reasons arising from the other proper uses of the particular forest. If there be other timbered areas on the public domain not now within the boundaries of the national forests of Nevada, or if there be water-catchment areas the control of which is of national rather than local importance, such areas should be set aside for these national purposes before any disposal is made of the public domain of which they are now a part.

The proper policy for other parts of the public domain can be determined only by an intensive study of existing conditions in each. There are some parts of the public domain that should be retained in public ownership because they are adapted to growing timber, and other areas are of public significance because they are suitable for national parks and monuments or the serving of other public interests. There is also a large, though vaguely defined, area in which the conservation of water and the protection of watersheds are matters of national concern.

As in Nevada, there are parts of the public domain in other States where existing possessory rights, in their complex interrelation with private lands, water rights, State lands, and various national reservations, should be considered carefully in any adjustment provided. It may be learned, after careful study, that the best adjustment is a regional one that does not conform even to State boundaries.

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[48] By water conservation is meant the regulation of the whole train of phenomena which commences with the fall of the water, as rain or snow, upon a catchment area, its proper protection and storage, its properly regulated flow to lower levels with the maximum development of power and the minimum of damage as an erosive agent, and its final use for irrigation and municipal water supplies.

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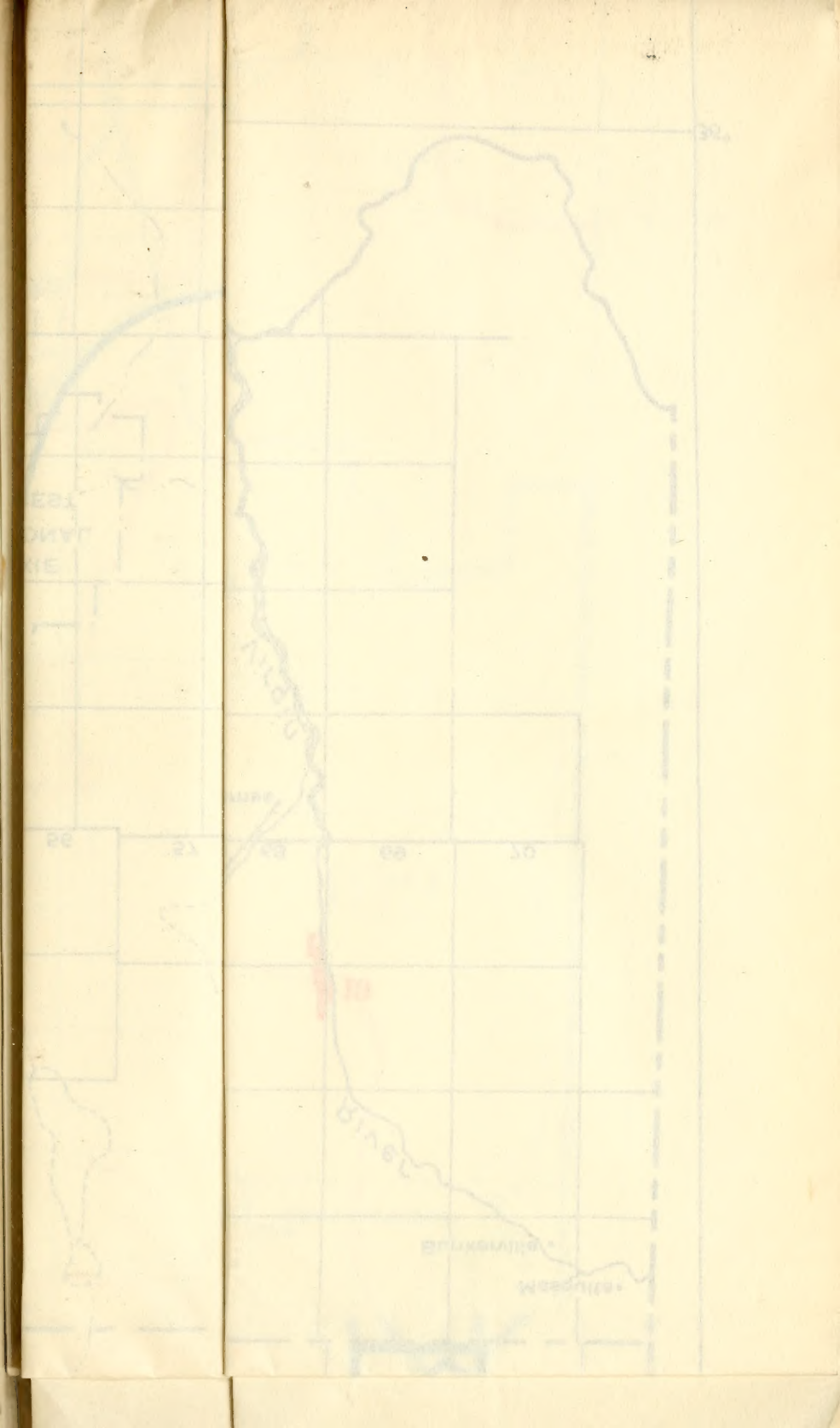
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